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PUSH FORCES EXERTED IN SIXTY-FIVE COMMON WORKING POSITIONS

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13. ABSTRACT Experiments were conducted to measure the maximum isometric horizontal push forces exorable in 65 common working positions. The subjects (45 male college students), while pushing horizontally, either anchored their feet against a footrest or braced themselves against a vertical wall. Means, standard deviations, and 5th percentiles of the forces exerted are reported. Male operators can exert horizontal static forces of at least 25 kp (55 lb) pushing with one hand, at least 9 kp (110 lb) pushing either with both hands or with the shoulder, and at least 75 kp (165 lb) pushing with the back - provided they anchor their feet or, better, brace themselves against a vertical wall. A vertical push panel that allows most subjects to exert maximum horizontal force has a rough surface, is 40 cm (16 in.) wide, and extends from 50 cm (20 in.) above the floor to 125 cm (50 in.) above the floor.			

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Foreword

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This technical report has been reviewed and is approved.

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Section I

INTRODUCTION

Muscular strength is the capacity to exert force under static conditions. During the contraction period, the length of the muscles involved stays constant. No limb motion accompanies this isometric force exertion. By excluding dynamics, the experimenter avoids complicated physics, but he also finds himself in the dilemma that the strength data he measures have rather limited application. They are directly meaningful only for static conditions when force exertion is not accompanied by motion.

In 1957 Hunsicker and Greey compiled some 80 studies on human muscle strength. Since then, at least 20 other studies have been reported, e.g., by Anthropology Section, 1963; Asmussen and Heebøll-Nielsen, 1961, 1962; Caldwell, 1959a, b, 1960, 1962, 1964a, b; Dempster, 1958, 1961; K. Fox, 1957; W. F. Fox, 1967; Garrett, Alexander, and Bennett, 1967; Konz and Day, 1966; Molbech, 1963; Pierce, 1960; Roberts, Provins, and Morton, 1959; Rohmert, 1960a, 1966; Streimer and Springer, 1963; Tornvall, 1963; and Watt, 1963.

Results of such studies that are significant for engineering purposes were recently compiled by Damon, Stoudt, and McFarland, 1966; Kroemer, 1967a; Lehmann, 1962; McCormick, 1964; Morgan et al, 1963; Murrell, 1965; Scherrer, 1967; Wilkie, 1960; and Woodson and Conover, 1964. Strength data also appear in military manuals, such as the Handbook of Instructions for Aerospace Personnel Subsystems Design (HIAPSD).

These publications provide rather complete information on the range of static forces that can be exerted by seated subjects, but very little information on standing subjects. Of the few force data of standing subjects, most were measured while the subjects posed in "standard" body postures, i.e., generally standing erect and with no other body support than the floor available.

While trying to push or pull very hard, a person generally does not stand erect, but rather inclines his body and bends his legs, trunk, and arms. According to the axiom of action=reaction, the force actively exerted is limited by the reaction force available. Hence, he tries to anchor his feet securely, and/or brace the body against a firm support, etc. In general, he seeks to position the body so that his strongest muscles can be fully activated, his body weight used, and the chain of force vectors from the supporting structures through his body to the point of force application kept as simple and effective as possible.

Dempster (1958) approached the problem of force capabilities of the standing operator in just such a "realistic" way. He measured the two-handed maximal *pull* forces of one subject in several common body postures. This report describes procedures and results of experiments conducted to measure static *push* forces exerted in common standing positions.

Section II

EQUIPMENT

The experimental equipment is shown in figure 1 and includes the following items:

1. The three-dimensional framework is constructed of 2.5 by 2.5 cm angle irons and is 230 cm long, 230 cm high, and 75 cm deep. The bottom and front are filled in with plywood. Along the long sides of the framework, the horizontal angle irons at the bottom and at the top have holes

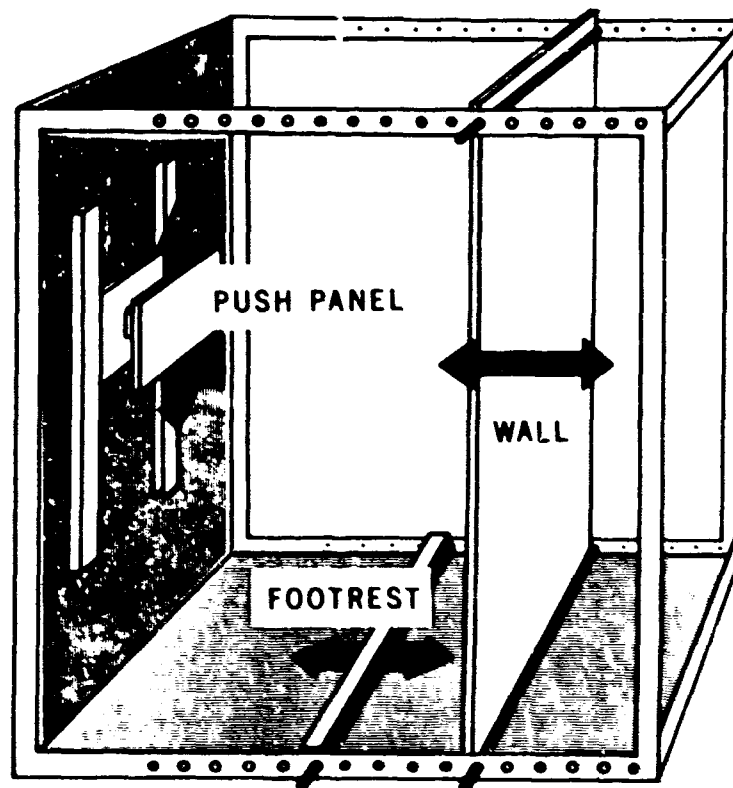


Figure 1. Experimental equipment: adjustable push panel, wall and footrest.

2 cm in diameter. Into these holes, iron rods (1.5 cm in diameter and 80 cm long) can be inserted horizontally and parallel to the front side of the frame. If only one rod is inserted into opposite holes of the bottom angles, a wooden *footrest* (61 by 6 by 6 cm) can be hooked to it, so that this footrest lies on the bottom plywood (which from now on is referred to as the "floor"). If one rod each is inserted horizontally into two bottom and two top holes, respectively, a removable *wall* can be hooked onto the top rod to rest against the bottom rod so that it does not give way if pressed against. This wall, 61 cm wide and 215 cm high, consists of plywood¹, reinforced on the back with aluminum angles.

By means of the holes in the frame and the rods inserted into them, either the footrest or the wall can be adjusted in steps of 5 cm to distances from 25 to 200 cm from the stationary vertical plywood front.

2. The *push panel* consists of an oval-shaped ring of stainless steel, mounted centrally between two aluminum plates. These plates are 25 cm wide, 20 cm high, and 1 cm thick; the horizontal distance between the two outside surfaces is 14 cm. One of the plates slides between two U-shaped aluminum angles, bolted vertically to the plywood which fills in the front side of the iron frame. By inserting pins into holes in one of the U-angles, the center of the protruding surface of the push panel can be adjusted in steps of 2 cm to heights between 35 and 160 cm above the floor.

Four strain gages are glued to the steel ring. By means of the usual Wheatstone Bridge arrangement, deflection of the steel ring resulting from force applied to the push panel is shown on a voltmeter or permanently recorded using a Sanborn 1500 recorder. After calibration of the recording system with lead weights, forces applied to the push panel can be read in kp*.

Due to design and arrangement of the push panel, only horizontal forces perpendicular to the push panel are recorded. Readings are taken at least to the next 2.5 kp when the force applied to the push panel is less than 90 kp. Above 90 kp, at least the next 5 kp are read.

*kp (kilopond, formerly called kilogram, kg) is the force which is exerted by a mass of 1 kg at standard gravity. 1 kp equals 2.205 pounds.

Section III

EXPERIMENTAL CONDITIONS

An attempt was made to imitate, within reasonable limits, all kinds of body supports and body postures that might occur while trying to push horizontally.

BODY SUPPORT

Two different conditions of support to the subject can be distinguished:

a. The subject stands on a flat horizontal floor. No vertical surfaces are provided against which he can anchor his body. Reaction forces to the push he exerts are provided only by friction between his shoes and the floor.

b. In addition to the floor, vertical surfaces are provided against which he anchors his feet and/or braces his body. Reaction forces to the push he exerts are partly, and sometimes only, provided by contact between parts of his body and the vertical surfaces perpendicular to the direction of push.

According to action=reaction, the amount of reaction force available to the subject determines the amount of force he can exert; he cannot exert any forces greater than the reaction forces available to him. If he stands on a flat floor — as in condition "a" — it is likely that the push force he exerts is not determined by his strength, but by his intention to prevent his feet from sliding on the floor so he won't fall. Under this condition, the exerted push force simply reflects the reaction force available to him at his shoes. Caldwell (1960), Dempster (1955, 1958) and Rohmert (1960a) showed how pull forces depend on reaction forces.

The reaction force preventing the subject from sliding on the floor depends on the coefficient of friction between his shoes and the floor and also on the force pressing shoes and floor together (this force is partly generated by his weight). Neither one of these two factors can be controlled easily. Therefore, it was decided to use in these experiments only infinite friction, or, in other words, an infinite reaction force. This was achieved by using a footrest on the floor. If the subject places a foot against the footrest, he cannot slide backward and infinite reaction force is available to him. This artifice assured that the push forces exerted by our subjects were independent of the friction between their shoes and the floor.

BODY POSTURE

A subject pushing against a vertical panel can either:

- a. Stand freely on a horizontal floor without any other body support than the floor and the footrest (this condition is called "free standing" from now on), or
- b. Brace himself against the vertical wall (called "braced" from now on).

Also, he can either:

- c. Exert horizontal forces in his midsagittal plane (forward or backward), or
- d. Push laterally.

From all possible combinations of these four variables, those were selected, according to common experience and to preliminary studies, that permit exertion of large push forces. For convenience, they are divided into various conditions as illustrated in figures 2, 3 and 4:

- Subject free stands, pushing either forward (experiment 1*) or laterally (experiment 2);
- Subject braces against a vertical wall, pushing in his midsagittal plane either forward (experiments 3, 4 and 5) or backward (experiment 6);
- Subject braces the shoulder(s) or one hand against a vertical wall, pushing with the preferred shoulder or with the preferred hand (experiments 7 through 10).

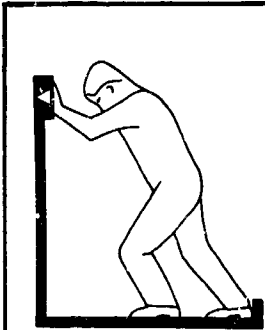
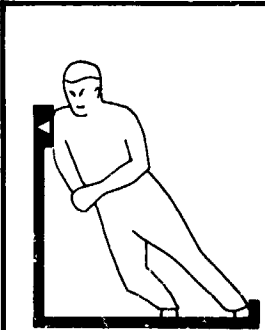
		
EXPERIMENT No.	1	2
HEIGHT ADJUSTMENTS of the push panel	70, 80, 90% of the individual Shoulder Height (Acromial Height) of the subjects	60, 70, 80%
DISTANCE ADJUSTMENTS between the push panel and the footrest	70, 80, 90% of the individual Acromial Height of the subjects	60, 70, 80, 90%

Figure 2. Subject free stands, pushing forward or laterally.

The body postures of the subjects are further determined and described by the adjustments of the push panel and of the footrest or of the wall, respectively.

In all but one series of experiments, the subjects had to apply force to the push panel either with their hands or with their shoulders. Since the flow of force had to pass through their should-

*Throughout this report, the following nomenclature is used: Each single push effort of a subject is called "trial." "Experiment" comprises a number of trials during which the subject maintains the same type of posture and during which body support (reaction force) is provided in the same way.

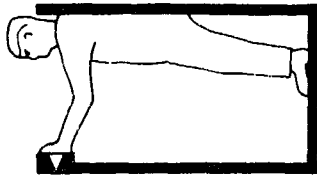
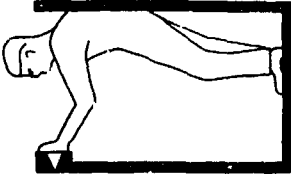
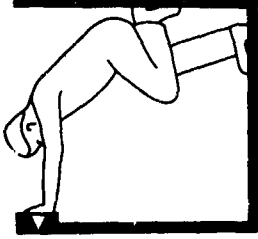
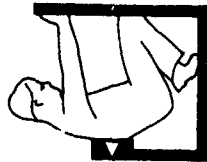
				
EXPERIMENT No.	3	4	5	6
HEIGHT ADJUSTMENTS of the push panel	100%	90%	50, 70, 90%	40%
of the individual Shoulder Height (Acromial Height) of the subjects				
DISTANCE ADJUSTMENTS between the push panel and the wall	50, 60, 70, 80, 90, 100%	70, 80, 90, 100, 110, 120%	80, 100, 120%	80, 90, 100, 110, 120, 130%
	of Thumb-tip Reach	of Thumb-tip Reach	of Acromial Height	of Thumb-tip Reach

Figure 3. Subject braces against a vertical wall, pushing forward or backward in his midsagittal plane.


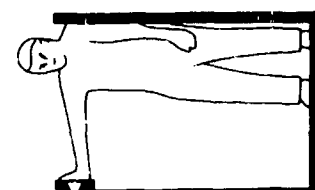
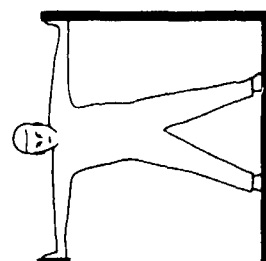
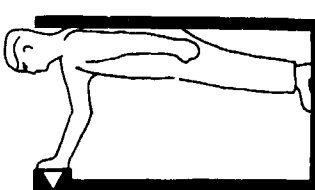
				
EXPERIMENT No.	7	8	9	10
HEIGHT ADJUSTMENT of the push panel	100%	100%	100%	100%
DISTANCE ADJUSTMENTS between the push panel and the wall	80, 90, 100% of Shoulder (Bideloid) Breadth	50, 60, 70, 80, 90, 100% of Lateral Thumb-tip Reach	50, 60, 70, 80, 90% of Span	50, 60, 70, 80, 90, 100% of Thumb-tip Reach

Figure 4. Subject braces the shoulder(s) or one hand against a vertical wall, pushing with the preferred shoulder or with the preferred hand.

ers each time, the height of the push panel was adjusted in fractions of the shoulder height (Acromial Height*) of each subject.

The horizontal distance between the vertical surface of the push panel and the opposing vertical surface of the footrest or of the wall, respectively, was also adjusted individually to suit the body dimensions of each subject. As figures 2, 3 and 4 show, the distances to the push panel were adjusted to the individual forward reach capability (Thumb-tip Reach, experiments 3, 4, 6 and 10) or to the lateral reach (experiment 8), to shoulder breadth (experiment 7), and to Span (experiment 9). The individual shoulder height (Acromial Height) was used as the basis for the distance adjustment if no other body dimension was obviously related to the experimental conditions (experiments 1, 2 and 5). The fact that the push panel was adjusted to individual body dimensions rather than to given absolute measures should facilitate application of the experimental data to other subject populations.

The distance adjustments were selected to cover the range from very (too) close to very (too) far. Thus, the experiments covered the total range of the subject's reach capabilities.

Section IV

PROCEDURE

The experiments were conducted in an air-conditioned room in which one or two experimenters and one subject, seldom two subjects, were present.

When the subject first came to the laboratory his body dimensions were measured.† Purpose and procedure of the experiments were explained. While the subject was urged to exert his maximum push force and to maintain it for 5 seconds in each trial, he was also told to avoid any postures or strains that might lead to injuries.

Using a table of random numbers, the sequence of experiments 1 to 10, and the sequence of trials were established.

The experimenter adjusted the height of the push panel and the distance between the push panel and the wall or the footrest, respectively. In general terms, he instructed each subject as to which body posture was to be used and which parts of the body were required or allowed to be braced against the wall or the footrest. He told the subject that his palms must be held flat against the push panel when pushes were to be exerted with the hands. The experimenter made it clear to the subject that within the given limits he was free to choose any body posture that seemed to be most appropriate.

When the subject had assumed the appropriate body posture, he was given an oral "start" signal upon which he began to push on the dynamometer. The experimenter counted aloud each second until the fifth, after which the subject relaxed. Every subject exerted his maximal push force once under each of the experimental conditions.

Each subject completed the 65 trials during two or more sessions on separate days. Since force had to be exerted in each trial for only 5 seconds and since ample time for rest and recovery was

*For definitions of the body dimensions see Appendix II.

†A data blank is reproduced in Appendix I.

provided between each trial, muscle fatigue (Caldwell 1961, 1964b; Rohmert 1960b, 1961) could not occur.

Each subject had been told that he should maintain a maximum push force steadily over a period of 5 seconds, and that short-time peak forces were not desired. After a build-up of force during the first second, a rather constant force level was generally observed until the force dropped during the last second. Each subject's score was obtained by calculating the mean of the forces applied during the two consecutive-second time period that yielded the highest mean force over any two consecutive seconds and during which the forces applied were the most constant.* After each force exertion the subjects were informed about the forces they had achieved.

Section V

SUBJECTS

Forty-five male students at the University of Dayton, Dayton, Ohio, served as subjects in the main part of this study. They took part voluntarily and were paid by the hour. The experimenter did not attempt to select certain subjects, but none were admitted with disabilities that would prevent exertion of push force.

On each of the subjects, 27 body dimensions were measured, also noted were age and handedness. Appendix I is a sample of the data blank used for the measurements. The dimensions are defined in Appendix II.

In table I, the anthropometric data of the 45 subjects are listed together with the relevant dimensions of 2420 rated officers of the United States Air Force.

To check the consistency of our data, the total sample of 45 subjects was arbitrarily divided into two subgroups of 29 and 16 subjects each. No significant differences between the anthropometric data nor between the exerted push forces of the two groups were observed. In a pilot study, 15 members of our laboratory exerted their maximal push forces in each trial of experiment 1. Their force data do not significantly differ from those recorded on the 45 subjects, although the age distribution of the laboratory personnel was distinctly different (mean 26.1 years, SD 7.4 years) as opposed to the students (mean 20.7 years, SD 1.7 years).

*As a later investigation (Kroemer and Howard, 1968) showed, any other mean force over the 2nd, 3rd, or 4th second would have yielded a result not significantly different statistically from the average of these "selected two" seconds.

TABLE I

Anthropometric data of the subjects as compared to USAF personnel*. All dimensions in centimeters (cm) except weight in kilograms (kg), grip strength in kiloponds (kp), age in years, and handedness in percent (%).

Dimension	Subjects (n=45)		USAF (n= 2420)	
	Mean	SD	Mean	SD
1. Weight	76.5	11.1	78.9	9.7
2. Grip Strength I	54.9	7.6	56.4	7.6
3. Stature	177.4	5.1	177.3	6.2
4. Acromial Height, Right	145.8	4.6	145.2	5.8
5. Tibiale Height, Right	48.8	2.5	----	----
6. Biceps Circ, Right				
Flexed	32.0	2.6	32.7	2.3
Relaxed	29.5	2.7	30.8	2.3
7. Biceps Circ, Left				
Flexed	31.5	2.7	32.1	2.2
Relaxed	29.2	2.6	30.4	2.3
8. Upper Thigh Circ, Right	55.5	5.0	58.8	4.4
9. Lower Thigh Circ, Right	40.5	3.5	----	----
10. Calf Circ, Right	36.9	2.6	37.2	2.3
11. Calf Circ, Left	36.7	2.5	36.9	2.2
12. Grip Strength II	55.4	8.1	----	----
13. Lat. Thumb-tip Reach	108.9	4.0	----	----
14. Thumb-tip Reach	82.2	4.4	80.3	4.0
15. Span	184.2	6.3	----	----
16. Humeral Breadth, Right	7.1	0.3	7.1	0.4
17. Humeral Breadth, Left	7.1	0.3	7.1	0.4
18. Femoral Breadth, Right	9.4	0.5	10.0	0.4
19. Femoral Breadth, Left	9.4	0.5	10.0	0.5
20. Sitting Height	91.8	3.2	93.2	3.2
21. Knee Height, Right	57.2	2.3	----	----
22. Bideloid Breadth	48.3	2.5	48.2	2.6
23. Buttock-Knee Length	61.7	2.6	60.4	2.7
24. Triceps Skinfold, Right	1.4	0.5	1.3	0.5
25. Juxtanipple Skinfold, Right	1.8	0.7	1.4	0.7
26. Subscap. Skinfold, Right	1.5	0.6	1.4	0.5
27. Grip Strength III	55.6	8.0	----	----
Age	20.7	1.7	30.0	6.3
Handedness: Right	84		89	
Left	13		9	

*Clauser, C. E., et al. Anthropometry of Air Force Rated Officers - 1967. AMRL Technical Report in preparation.

Section VI

RESULTS

The results of the experiments are presented in figures 5 through 14. In each of the tables, the experimental conditions and results are reported in the same manner.

Illustrated by a sketch of the subject's posture, indicated are: (a) in which direction (e.g., forward) and with which part of the body (e.g., with both hands) the subjects applied force to the push panel, (b) whether reaction force to the exerted push was supplied to the operator by a footrest or by a wall against which he could brace himself, (c) which additional requirements were imposed on the subjects (e.g., keep the sole of the shoe flat on the floor).

For each trial*, the mean force is given as well as the standard deviation (SD), the 5th percentile value (5th%)†, and the number of subjects. In addition, the height adjustment of the push panel above the floor as well as the adjustment of the horizontal distance between the push panel and the footrest or the vertical wall (whichever was used) are reported (a) in percent of the subjects' body dimensions and (b) in centimeters (mean and standard deviation).

The tabulated forces are also presented in graphic form. Means, standard deviations, and 5th percentile values are plotted for each trial against the horizontal distances between push panel and footrest or wall, respectively.

Commentaries on the experimental results follow each of the figures 5 through 15. The remarks are partially based on the outcome of t-tests, carried out to determine whether statistically significant differences between the mean forces existed. The formula used was

$$t = \frac{\bar{F}}{SD_r} \sqrt{n-1}$$

where

\bar{F} is the mean of the differences between each subject's forces which he exerted under the two compared conditions,

SD_r is the standard deviation of the differences,

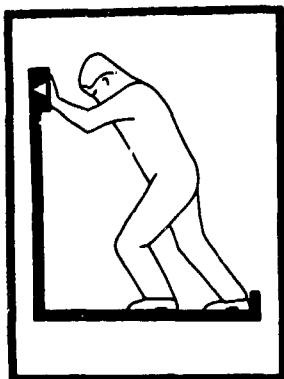
n is the number of differences, i.e., the number of pairs of scores.

The null hypothesis was rejected if the t-value was beyond the 5% limit of the two-tailed test.

*The numbering of the trials does not indicate the order of testing, which was at random; see Section IV.

†This is the force the weakest 5% of the subject population could not exceed, while the remaining 95% were stronger. The 5th percentile value can be approximated by deducting 1.65 standard deviations from the mean. The 5th percentile values reported here, however, are based on the original scores obtained in the experiments.

Experiment 1



FORWARD PUSH WITH BOTH HANDS

REACTION FORCE PROVIDED BY FLOOR AND FOOTREST

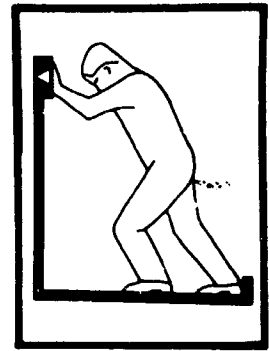
At least one foot must be against the footrest with the sole flat on the floor.

Trial No.	MAXIMAL STATIC PUSH FORCES				ADJUSTMENTS OF PUSH PANEL AND FOOTREST					
	exerted horizontally on the push panel				HEIGHT of the center of the push panel			Horizontal DISTANCE between push panel and footrest		
	Mean kp	SD kp	5th %	N	% of AH*	Mean cm	SD cm	% of AH*	Mean cm	SD cm
1.1	44.1	9.7	29.6	41	90	131.3	4.2	70	102.0	3.2
1.2	45.7	9.5	30.9	41	90			80	116.6	3.7
1.3	49.4	8.1	37.5	41	90			90	131.3	4.2
1.4	55.6	12.9	36.1	41	80	116.6	3.7	70	102.0	3.2
1.5	55.3	12.5	38.0	41	80			80	116.6	3.7
1.6	54.3	8.3	39.8	41	80			90	131.3	4.2
1.7	63.6	15.0	41.2	41	70	102.0	3.2	70	102.0	3.2
1.8	70.1	15.7	48.7	41	70			80	116.6	3.7
1.9	59.7	13.5	38.6	41	70			90	131.3	4.2

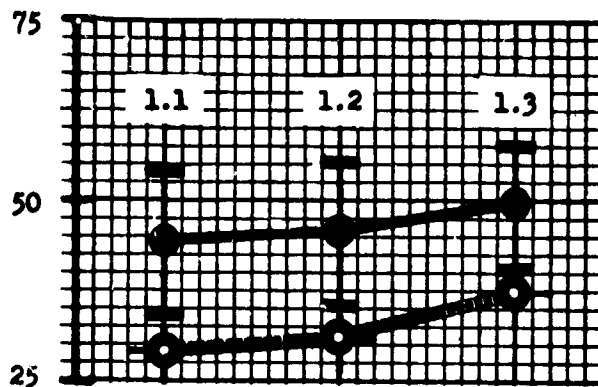
*Acromial Height (Shoulder Height); see Appendix II.

Figure 5. Results of experiment 1.

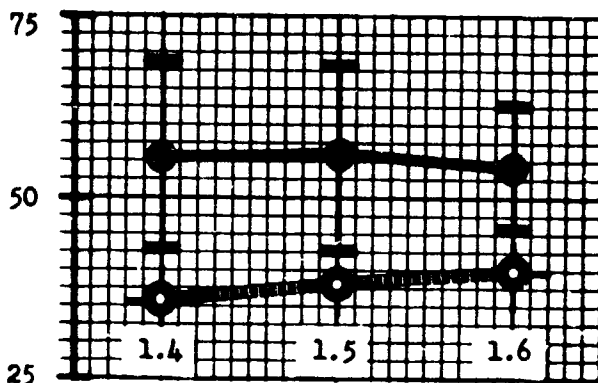
Experiment 1



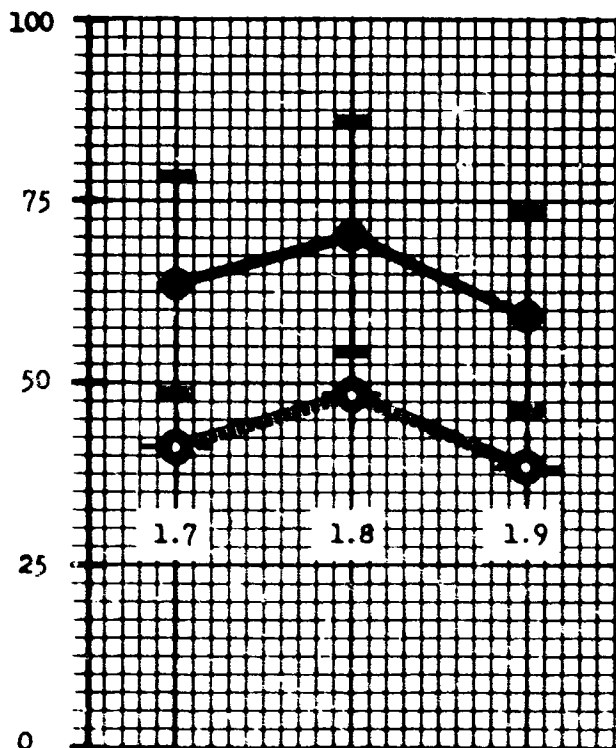
Force
in kp



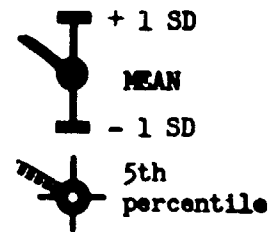
Push panel
at
90%
of
Acromial
Height



Push panel
at
80%
of
Acromial
Height



Push panel
at
70%
of
Acromial
Height



DISTANCE BETWEEN PUSH PANEL AND FOOTREST

Body Position

Forces

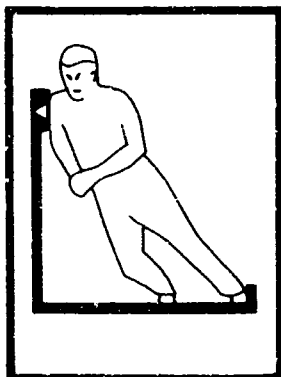
1.2	o								o = Null hypothesis maintained.
1.3	s	s							s = Null hypothesis rejected: forces exerted at the two compared conditions are significantly different from each other.
1.4	s	s	s						
1.5	s	s	s	o					
1.6	s	s	s	o	o				
1.7	s	s	s	s	s	s			
1.8	s	s	s	s	s	s	s		
1.9	s	s	s	s	s	s	s	s	
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	

14

Conclusion

Within the experimental limitations, reducing the height of the push panel from 90 to 80 or 70% of Acromial Height resulted in statistically significant gains with respect to the mean forces that could be applied to the push panel. If height and horizontal distance each are adjusted to approximately three-fourths of the individual's shoulder height, the diagonal distance between push panel and footrest is close to the subject's shoulder height. Leaning forward steeply, the subject can "wedge" his body between push panel and footrest and use his muscular strength and his body weight in the most effective way. In this condition, forces of about 40 kp could be exerted even by weak (5th percentile) subjects.

Experiment 2



LATERAL PUSH WITH THE SHOULDER

REACTION FORCE PROVIDED BY FLOOR AND FOOTREST

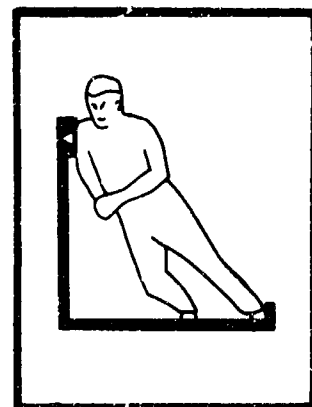
The push is exerted with the preferred shoulder. At least one foot must be against the footrest with the sole flat on the floor.

Trial No.	MAXIMAL STATIC PUSH FORCES				ADJUSTMENTS OF PUSH PANEL AND FOOTREST					
	exerted horizontally on the push panel				HEIGHT of the center of the push panel			Horizontal DISTANCE between push panel and footrest		
	Mean kp	SD kp	5th %	N	% of AH*	Mean cm	SD cm	% of AH*	Mean cm	SD cm
2.1	53.1	13.3	33.0	43	80	116.6	3.7	60	87.4	2.8
2.2	63.2	13.2	45.1	43	80			70	102.0	3.2
2.3	64.8	13.6	40.9	43	80			80	116.6	3.7
2.4	59.2	11.2	41.5	43	70	102.0	3.2	60	87.4	2.8
2.5	71.2	12.6	56.3	43	70			70	102.0	3.2
2.6	74.3	14.3	57.4	43	70			80	116.6	3.7
2.7	77.6	17.5	53.7	43	60	87.4	2.8	70	102.0	3.2
2.8	87.1	18.0	62.1	43	60			80	116.6	3.7
2.9	80.8	14.7	54.6	43	60			90	131.3	4.2

*Acromial Height (Shoulder Height); see Appendix II.

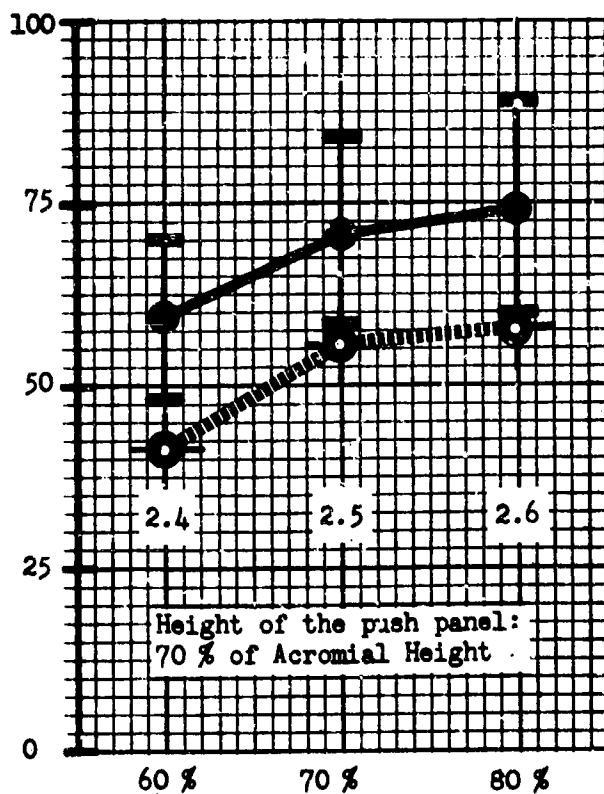
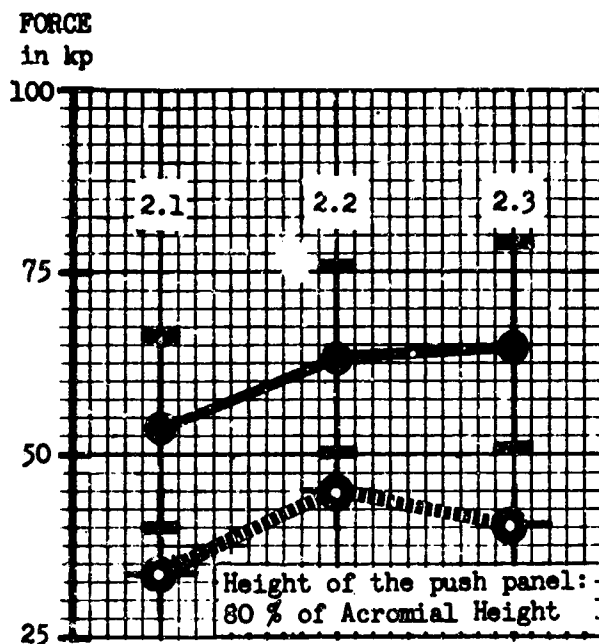
Figure 3. Results of experiment 2.

Experiment 2

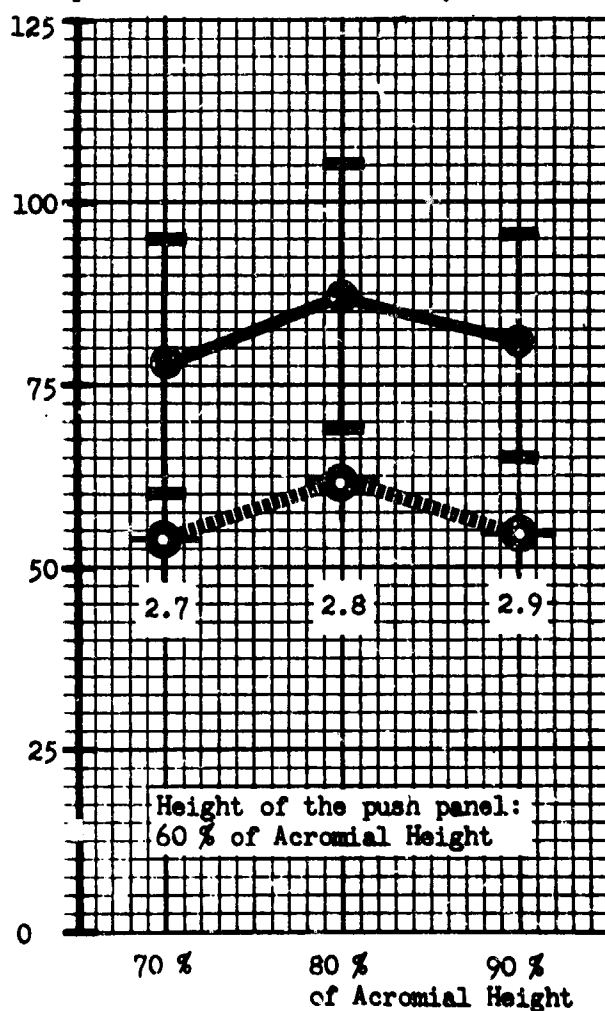


+ 1 SD
MEAN
- 1 SD

5th percentile



FORCE in kp



DISTANCE BETWEEN PUSH PANEL AND FOOTREST

Body Position

Forces

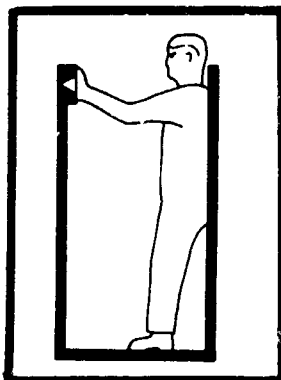
[illegible]

- **Constant Horizontal Distance Between Push Panel and Footrest** – Reducing the height of the push panel from 80 to 70% and even to 60% of Acromial Height led to increased force. This held true for all spacings, i.e., for 60% (compare 2.1 and 2.4), 70% (compare 2.2, 2.5 and 2.7) and for 80% of Acromial Height (compare 2.3, 2.6 and 2.8),

Conclusion

Within the experimental limits, reducing the height of the push panel from 80 to 70 and 60% of Acromial Height resulted in significant and considerable gains with respect to the mean forces that could be applied to the push panel. Largest forces were exerted while the subject leaned at approximately 45 degrees toward the push panel. This enabled him to "wedge" his body between push panel and footrest and to use his muscular strength and body weight in the most effective way. Height adjustments of the push panel to 60 or 70% of the individual's Acromial Height and to about three-fourths of the shoulder height for the horizontal distance between push panel and footrest allowed even weak subjects (5th percentile) to apply approximately 55 kp.

Experiment 3



FORWARD PUSH WITH BOTH HANDS

REACTION FORCE PROVIDED BY A VERTICAL WALL

Both shoulders must touch the wall.

Trial No.	MAXIMAL STATIC PUSH FORCES				ADJUSTMENTS OF PUSH PANEL AND WALL					
	exerted horizontally on the push panel				HEIGHT of the center of the push panel			Horizontal DISTANCE between push panel and wall		
	Mean kp	SD kp	5th %	N	% of AH*	Mean cm	SD cm	% of TR†	Mean cm	SD cm
3.1	59.3	14.6	30.3	39	100	145.9	4.6	50	41.0	2.2
3.2	68.0	16.3	41.4	40	100			60	49.3	2.6
3.3	100.0	27.6	57.7	39	100			70	57.5	3.1
3.4	130.9	40.6	58.0	40	100			80	65.7	3.5
3.5	99.9	30.8	44.0	40	100			90	74.0	4.0
3.6	65.9	25.9	23.3	35	100			100	82.2	4.4

*Acromial Height (Shoulder Height); see Appendix II.

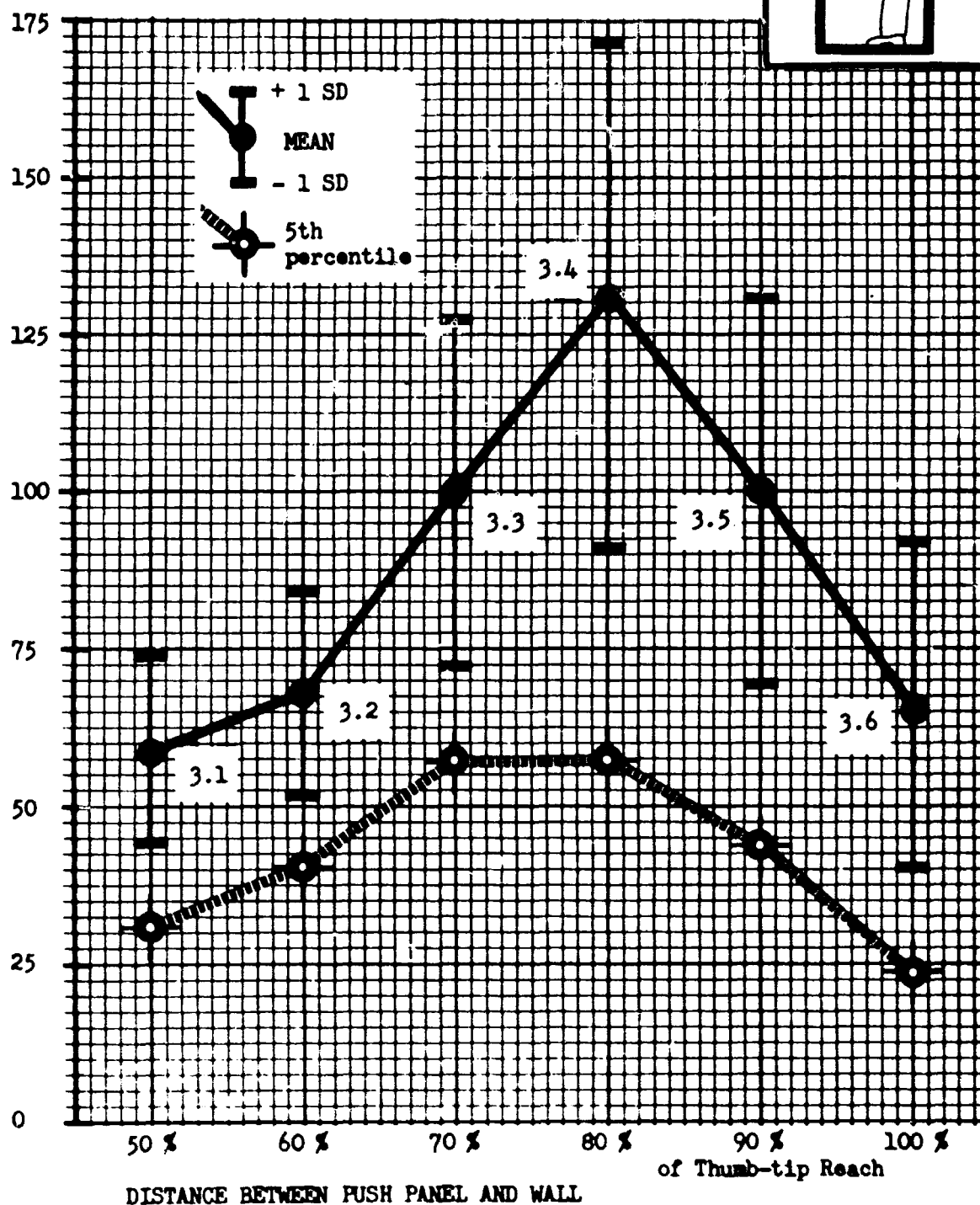
†Thumb-tip Reach; see Appendix II.

Figure 7. Results of experiment 3.

Experiment 3



Force
in kp



EXPERIMENT 3 -- Comments

Body Position

While pushing forward with both hands, the subjects placed their feet below or slightly forward of their trunk. Since the subjects were required to keep both shoulders against the wall while pushing, they had to place their fingertips instead of their palms against the push panel when the distance between push panel and wall was adjusted to 100% of Thumb-tip Reach.

Forces

Statistics -- The magnitude of exerted forces and their spread of values are considerable, the means ranging from 59 to 131 kp. The statistical test of the differences between means yielded the following results:

3.2	s				
3.3	s	s			
3.4	s	s	s		
3.5	s	s	o	s	
3.6	s	o	s	s	s
	3.1	3.2	3.3	3.4	3.5

o = Null hypothesis maintained.

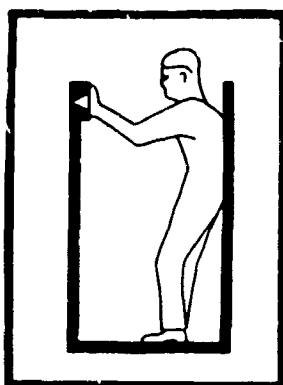
s = Null hypothesis rejected:
forces exerted at the two compared conditions are significantly different from each other.

Effects of Distance Adjustments -- Increasing the distance between push panel and wall from 50 to 80% of the individual Thumb-tip Reach allowed the subject to stretch his arms and thereby exert increasing forces. Further adjustments, however, reduced the amount of applied force considerably, since it became increasingly difficult to reach the push panel. Finally, force had to be applied with the fingertips instead of with the palms of the hand.

Conclusion

Adjustment of the distance between push panel and wall to about three-fourths of the subject's Thumb-tip Reach was most effective for exertion of horizontal push force. In this experiment, the straight arms could be locked between push panel and wall. Reducing the distance to about half the reach distance or increasing it to full reach capability diminished the force substantially. When the distance corresponded to about three-fourths of the individual's reach distance, about 58 kp could be exerted even by weak subjects (5th percentile).

Experiment 4



FORWARD PUSH WITH BOTH HANDS

REACTION FORCE PROVIDED BY A VERTICAL WALL

The subject chooses which part of his back will touch the wall.

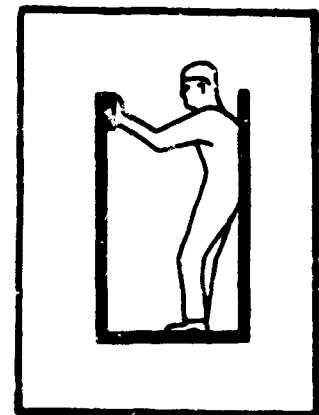
Trial No.	MAXIMAL STATIC PUSH FORCES				ADJUSTMENTS OF PUSH PANEL AND WALL					
	exerted horizontally on the push panel				HEIGHT of the center of the push panel			Horizontal DISTANCE between push panel and wall		
	Mean kp	SD kp	5th %	N	% of AH*	Mean cm	SD cm	% of TR†	Mean cm	SD cm
4.1	92.6	28.9	42.0	44	90	131.3	4.2	70	57.5	3.1
4.2	112.1	36.1	51.1	44	90			80	65.7	3.5
4.3	97.1	23.6	61.4	44	90			90	74.0	4.0
4.4	76.6	14.8	49.9	44	90			100	82.2	4.4
4.5	77.8	14.2	55.3	44	90			110	90.4	4.9
4.6	84.5	17.9	59.2	44	90			120	98.6	5.3

*Acromial Height (Shoulder Height); see Appendix II.

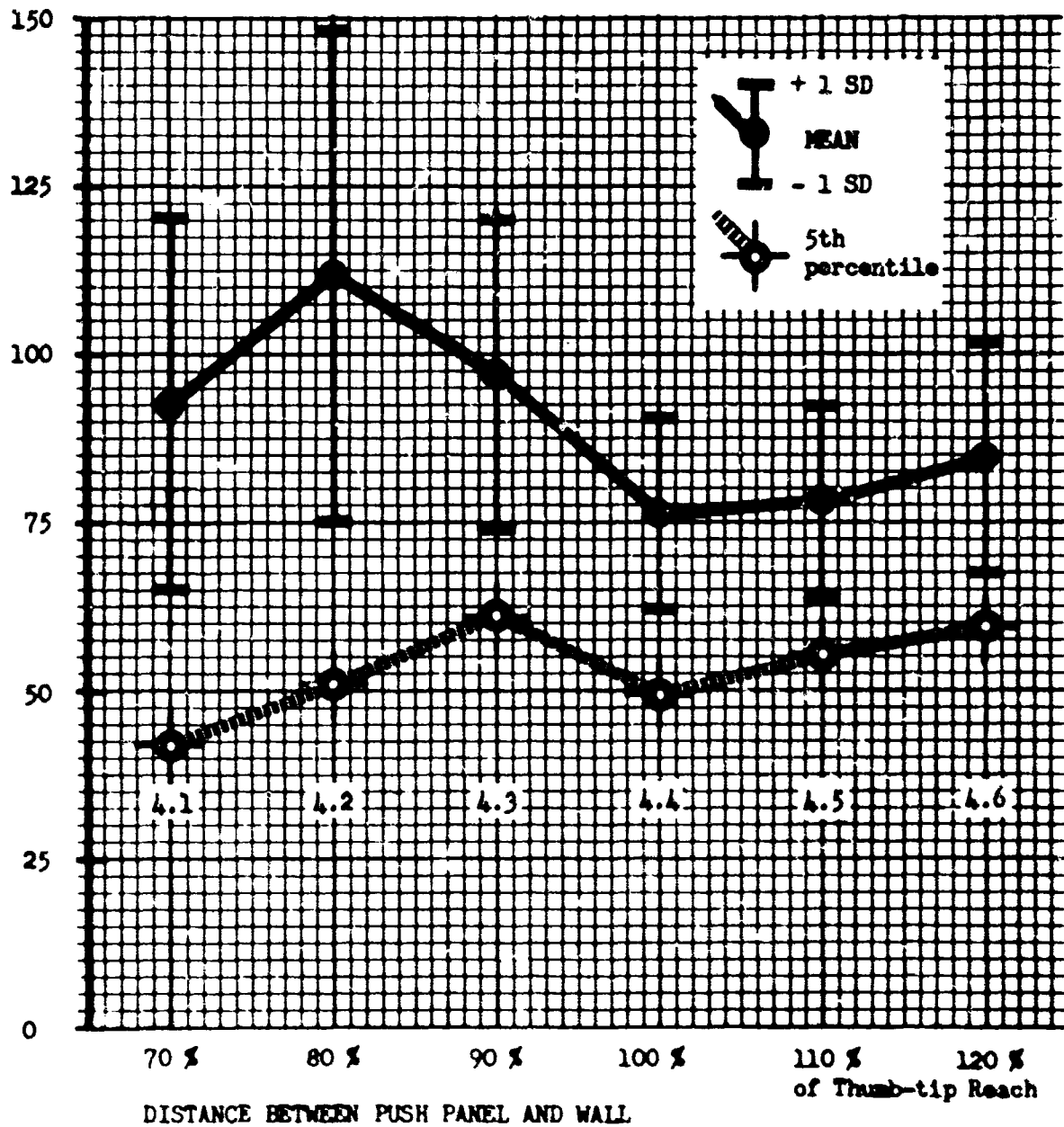
†Thumb-tip Reach; see Appendix II.

Figure 8: Results of experiment 4.

Experiment 4



FORCE
in kp



EXPERIMENT 4 - Comments

Body Position

The subjects normally kept their shoulders against the wall when the distance between wall and push panel was short. For greater distances, they leaned forward, having the lower part of their backs against the wall. The subjects generally had their feet about parallel and placed them slightly in front of their trunks.

Forces

Statistics - The magnitude of forces exerted is considerable, but the spread of the means is rather small, reaching from 77 to 112 kp. The statistical test of the differences between the means yielded the following results:

4.2	s				
4.3	o	s			
4.4	s	s	s		
4.5	s	s	s	o	
4.6	o	s	s	s	s
	4.1	4.2	4.3	4.4	4.5

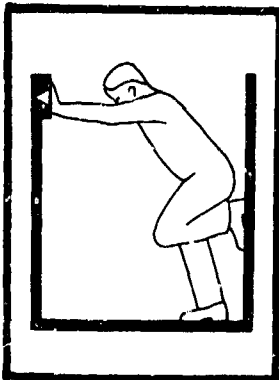
o = Null hypothesis maintained.
s = Null hypothesis rejected;
forces exerted at the two compared conditions are significantly different from each other.

Effects of Distance Adjustment - Maximal push forces could be exerted if the distance between push panel and wall was adjusted to between 70 and 90% of the individual's Thumb-tip Reach; the subjects could keep their shoulders against the wall and press forward with their arms almost or completely straight. Increasing the distance forced the subjects to lean forward from the wall, causing a distinctly less favorable flow of force vectors from the push panel through the arms and back to the wall; thus, only significantly smaller forces could be applied to the push panel.

Conclusion

Within the experimental limits, adjustment of the distance between push panel and wall to slightly less than the individual's Thumb-tip Reach resulted in relatively large push forces. If the distance was at least three-fourths of the individual's forward reach, even weak subjects (5th. percentile) could exert about 50 kp.

Experiment 5



FORWARD PUSH WITH BOTH HANDS

REACTION FORCE PROVIDED BY A VERTICAL WALL

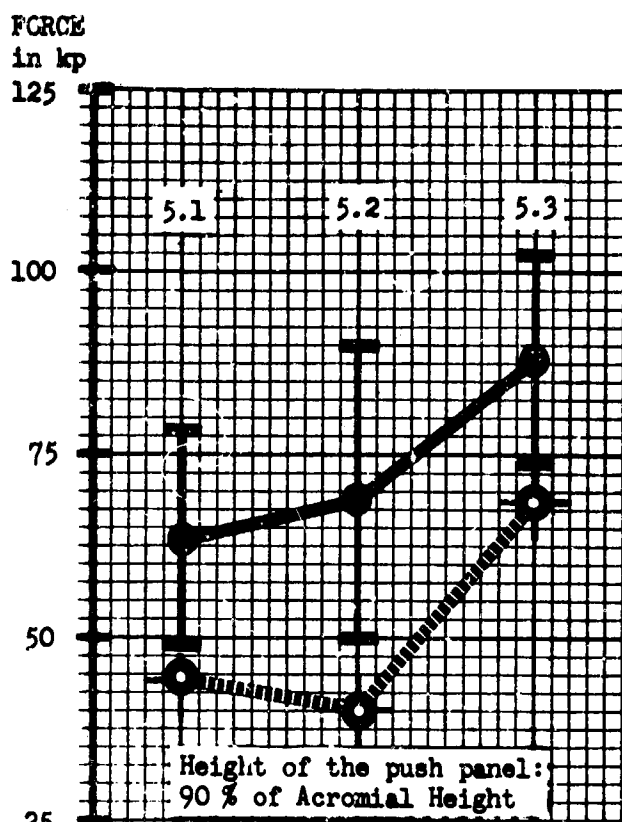
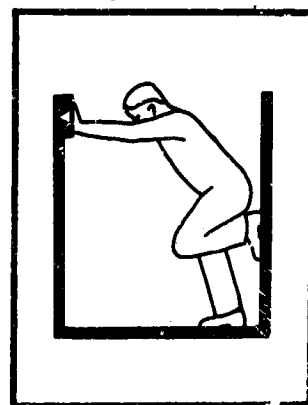
One foot must be placed against the wall.

Trial No.	MAXIMAL STATIC PUSH FORCES				ADJUSTMENTS OF PUSH PANEL AND WALL					
	exerted horizontally on the push panel				HEIGHT of the center of the push panel			Horizontal DISTANCE between push panel and wall		
	Mean kp	SD kp	5th %	N	% of AH*	Mean cm	SD cm	% of AH*	Mean cm	SD cm
5.1	63.7	15.0	44.6	42	90	131.3	4.2	80	116.6	3.7
5.2	69.1	19.9	40.1	42	90			100	145.9	4.6
5.3	88.0	14.4	63.9	37	90			120	175.0	5.6
5.4	73.0	16.5	50.0	41	70	102.0	3.3	80	116.6	3.7
5.5	74.5	23.8	45.5	42	70			100	145.9	4.6
5.6	83.6	14.1	60.9	37	70			120	175.0	5.6
5.7	67.7	18.0	39.4	41	50	72.8	2.4	80	116.6	3.7
5.8	78.7	22.0	47.7	42	50			100	145.9	4.6
5.9	79.5	16.8	57.9	37	50			120	175.0	5.6

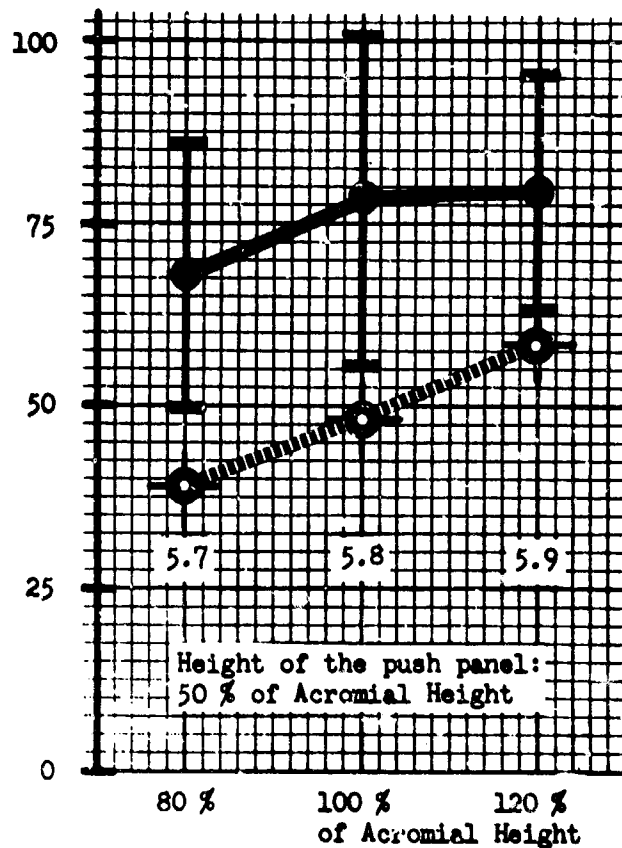
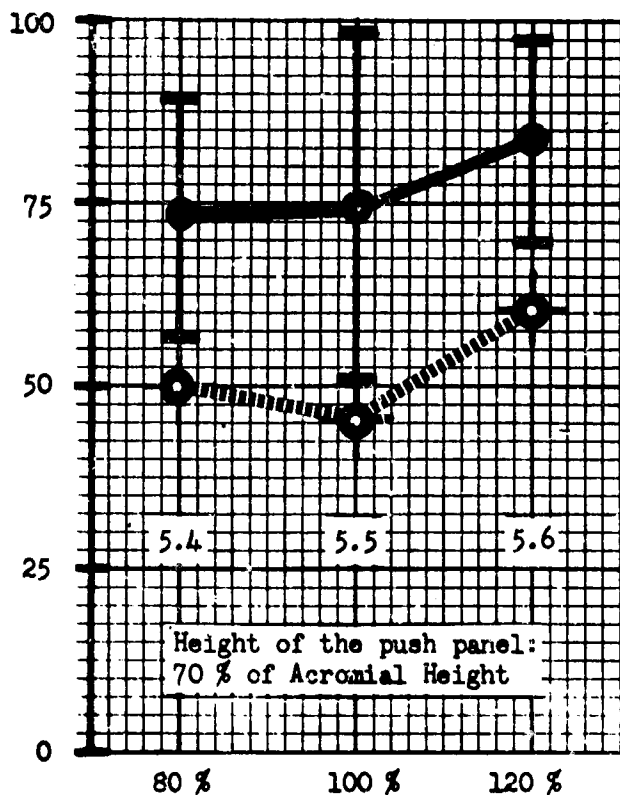
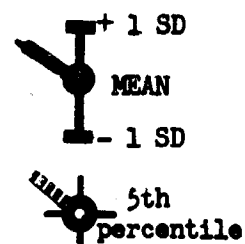
*Acromial Height (Shoulder Height); see Appendix II.

Figure 9: Results of experiment 5.

Experiment 5



FORCE in kp



DISTANCE BETWEEN PUSH PANEL AND WALL

Body Position

Forces

5.2	o = Null hypothesis maintained.							
5.3	s = Null hypothesis rejected: forces exerted at the two compared conditions are significantly different from each other.							
5.4	s	s						
5.5	s	o	s					
5.6	s	o	s	o				
5.7	s	s	s	s	s			
5.8	o	o	s	o	o	s		
5.9	s	s	s	o	o	o	s	o
	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8

- **Constant Distance between Push Panel and Wall** – At a distance corresponding to 80% of the individual's Acromial Height, lowering the height of the push panel from 90% of the Acromial Height to 70% brought about a small but significant increase in exertable force; further lowering to 50% of Acromial Height did not show any results.

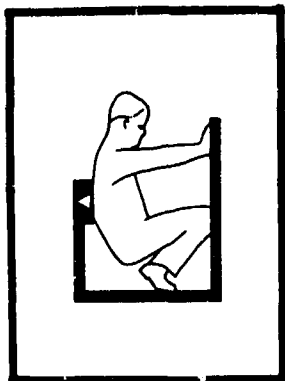
If the distance between the push panel and wall was equal to the shoulder height, lowering the push plate from 90 to 70%, or from 70 to 50% of Acromial Height did not cause any significant gains in force, although there was a significant but small increase in force in the lowest as compared to the highest adjustment.

At a distance adjusted to 120% of Acromial Height, lowering the push panel from 90 to 70% of Acromial Height resulted in reducing the force that could be applied to it. A further reduction at half shoulder height is statistically insignificant.

Conclusion

Reducing the height of the push panel from 90 to 70% of Acromial Height brought about a gain in exertable force when the distance between the push panel and wall was small (70% of Acromial Height). The subjects could lean forward towards the push panel and wedge their bodies between wall and push panel, keeping their arms bent and the push panel close to chest and chin. If, in contrast, the distance between push panel and wall was large (120% of Acromial Height), the highest adjustment of the push panel (to 90% of Acromial Height) enabled the subjects to lock their bodies with arms straight between the opposing surfaces and to exert larger forces. The differences between the measured forces are, however, rather small. At any adjustment, even weak subjects (5th percentile) could exert at least 40 kp.

Experiment 6



BACKWARD PUSH

REACTION FORCE PROVIDED BY A VERTICAL WALL

The subject chooses with which part of his back he will push. He also decides whether and how to place his hands, knees, or feet against the wall.

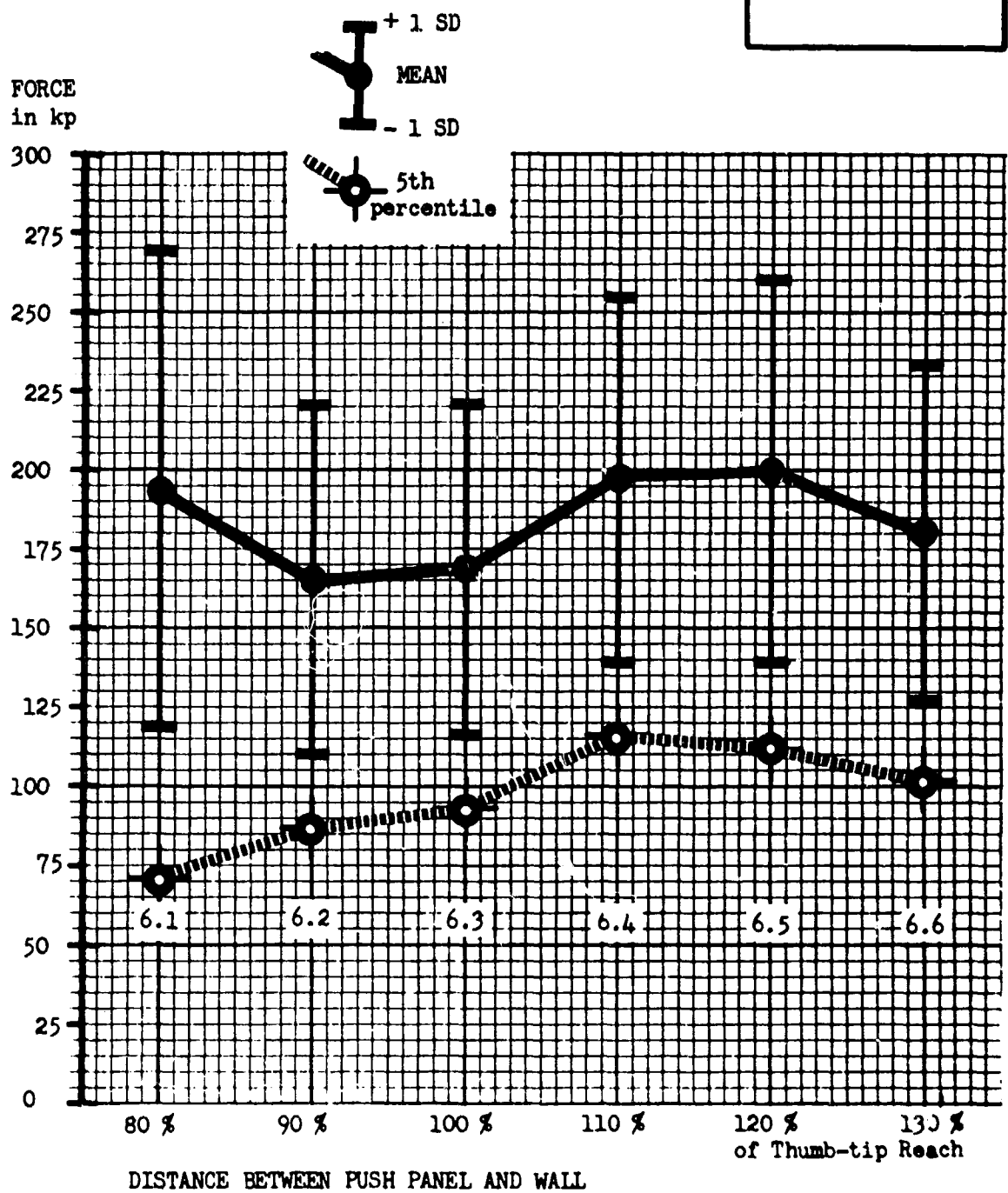
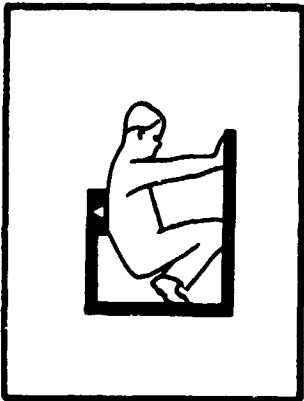
Trial No.	MAXIMAL STATIC PUSH FORCES				ADJUSTMENTS OF PUSH PANEL AND WALL					
	exerted horizontally on the push panel				HEIGHT of the center of the push panel			Horizontal DISTANCE between push panel and wall		
	Mean kp	SD kp	5th %	N	% of AH*	Mean cm	SD cm	% of TR†	Mean cm	SD cm
6.1	194.0	75.5	71.6	43	40	58.3	2.0	80	65.7	3.5
6.2	165.0	55.0	87.3	43	40			90	74.0	4.0
6.3	198.5	51.2	92.6	43	40			100	82.2	4.4
6.4	197.0	57.8	116.9	43	40			110	90.4	4.9
6.5	199.9	60.9	111.1	43	40			120	98.6	5.3
6.6	180.1	52.9	102.9	43	40			130	106.8	5.7

*Acromial Height (Shoulder Height); see Appendix II.

†Thumb-tip Reach; see Appendix II.

Figure 10. Results of experiment 6.

Experiment 6



EXPERIMENT 6 — Comments

Body Position

No subject had any difficulty executing this backward push, although some took a relatively long time to find the most suitable position. For the short distances between the push panel and wall, they generally had the push panel at the middle part of their backs, their arms held straight with their hands against the wall, and their legs bent and the knees against the wall. For the long distances between the push panel and wall, however, the subjects had the lower part of their backs against the push panel, their legs more or less straight, and both feet against the wall; often, they lifted their bodies off the floor, wedged between the push panel and the wall with both feet flat against it.

Forces

Statistics — Very high forces were exerted together with a relatively small spread of the means. They lie between 165 and 200 kp. The statistical test of the differences between the means yielded the following results:

6.2	s				
6.3	s	o			
6.4	o	s	s		
6.5	o	s	s	o	
6.6	o	o	o	o	s
	6.1	6.2	6.3	6.4	6.5

o = Null hypothesis maintained.

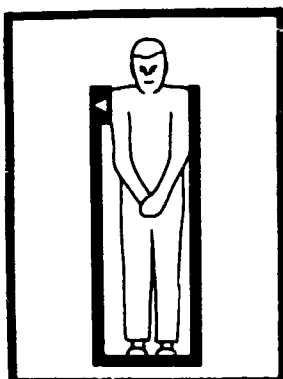
s = Null hypothesis rejected:
forces exerted at the two compared conditions are significantly different from each other.

Effects of Distance Adjustments — At the closest distance between the push panel and Acromial Height, that is, at 80% of Thumb-tip Reach, the subjects pushed very effectively backward, having their knees and hands braced against the wall. If the distance was increased, the wall was too far from the subject to be reached with hands and knees at the same time; this resulted in a significant reduction of the forces applied to the push panel. Enlarging the distance to 110 or 120% of the subject's Thumb-tip Reach, however, allowed them to push very strongly, since they could wedge themselves between push panel and wall with their legs straight and their feet against the wall. Frequently, the subjects lifted themselves completely off the floor. An additional increase of the distance between push panel and wall is 130% of Thumb-tip Reach proved to be too far to allow such push exertion and resulted in a loss of applicable force.

Conclusion

Of all experiments conducted, this manner of force application was by far the most effective. Pushing backwards either (a) with hands and knees against the wall at close distances or (b) at greater distances with legs straight and both feet against the wall, was highly successful. At the shorter distance, even weak subjects (5th percentile) could exert at least 75 kp. At the larger distances, over 100% of their reach capability, they could apply at least 100 kp.

Experiment 7



LATERAL PUSH EXERTED BY WEDGING THE SHOULDERS
BETWEEN PUSH PANEL AND VERTICAL WALL

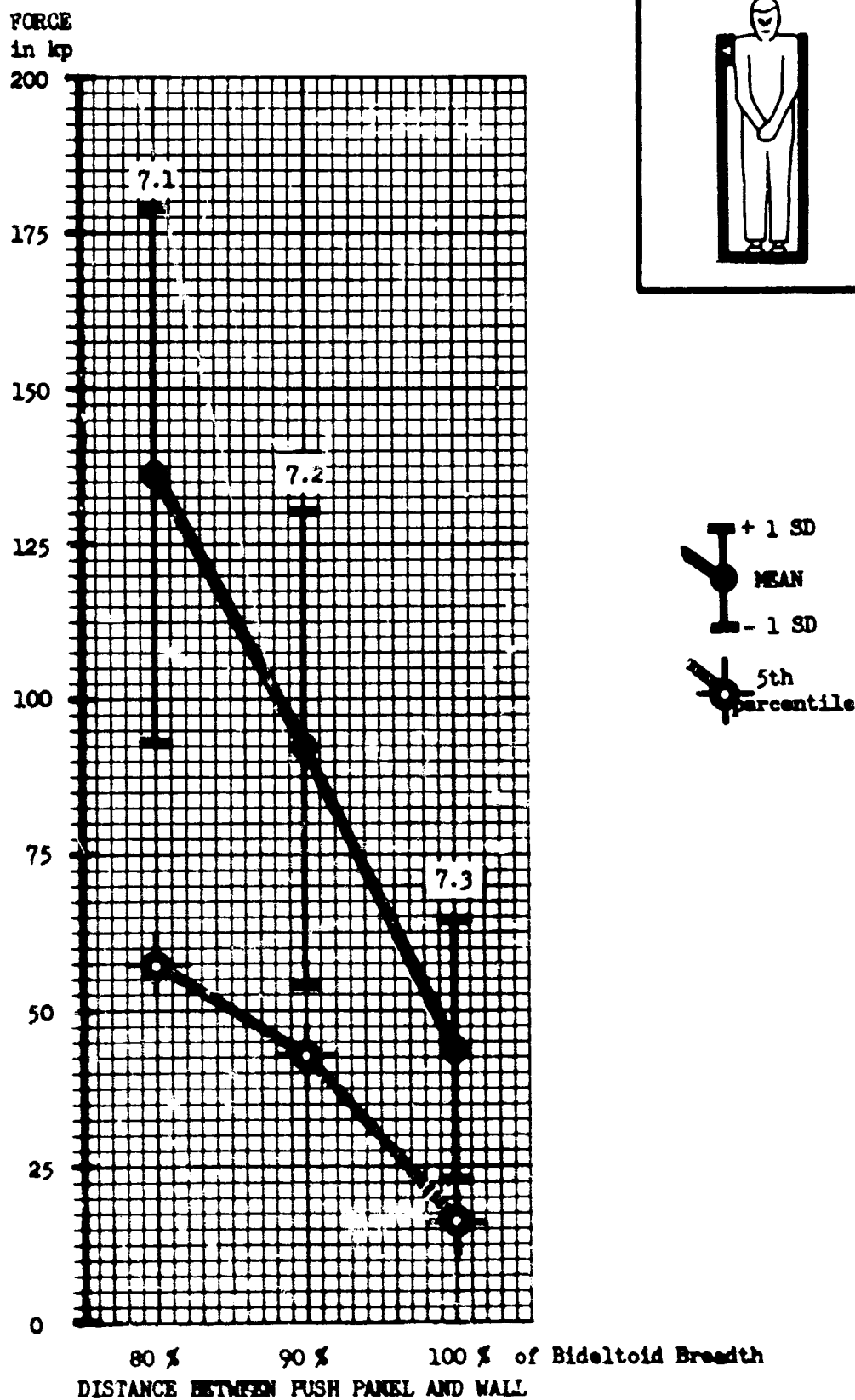
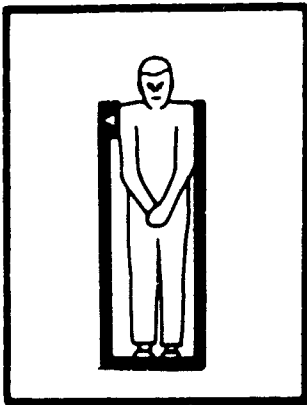
Trial No.	MAXIMAL STATIC PUSH FORCES				ADJUSTMENTS OF PUSH PANEL AND WALL					
	exerted horizontally on the push panel				HEIGHT of the center of the push panel			Horizontal DISTANCE between push panel and wall		
	Mean kp	SD kp	5th %	N	% of AH*	Mean cm	SD cm	% of BB†	Mean cm	SD cm
7.1	135.9	42.6	57.6	42	100	145.8	4.6	80	38.9	2.4
7.2	91.6	39.0	42.9	42	100			90	43.6	2.7
7.3	43.3	20.7	16.4	25	100			100	48.7	3.1

*Acromial Height (Shoulder Height); see Appendix II.

†Bideloid Breadth (Shoulder Breadth); see Appendix II.

Figure 11. Results of experiment 7.

Experiment 7



EXPERIMENT 7 - Comments

Body Position

In the two shorter distance adjustments between push panel and wall, no difficulties in body placement and positioning were encountered. Although the adjustment to 80% of the individual's Bideloid Breadth was rather narrow, it could be used by all subjects since the center of the push panel was at Acromial Height, which is somewhat higher than the point at which the largest Bideloid Breadth occurs. When distance between the push panel and wall was greatest, however, 17 of the 42 subjects could not apply any force at all to the push panel in the required way; for them, a distance corresponding to 100% of their Bideloid Breadth at Acromial Height was too ample for their shoulders.

Forces

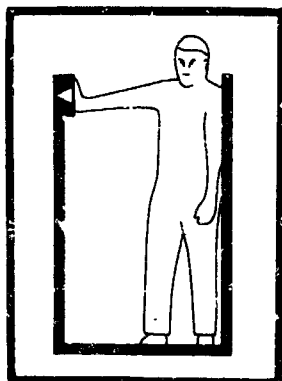
Statistics - The range of exerted forces is very large, the means being 136, 92, and 43 kp, respectively, at the three distance adjustments. All differences between the means were found to be highly significant statistically.

Effects of Distance Adjustments - At the shortest distance adjustment, 80% of Bideloid Breadth, the subjects could exert rather large forces by wedging their shoulders between wall and push panel. At a distance corresponding to 90% of Bideloid Breadth, their shoulders were much less compressed and the force that they could apply to the push panel by attempting lateral expansion of their shoulders significantly reduced. The widest adjustment, 100% of Bideloid Breadth between the push panel and wall, proved to be too great for many subjects. The remaining subjects could apply only relatively small forces.

Conclusion

This manner of exerting force appears to be rather impractical. Only in very uncomfortable narrow spaces, which are distinctly smaller than shoulder breadth, can large forces be exerted. If the space is widened only slightly, a steep decline of the exerable force occurs.

Experiment 8



LATERAL PUSH WITH ONE HAND

REACTION FORCE PROVIDED BY A VERTICAL WALL

The push is exerted with the preferred hand; the opposite shoulder is against the wall.

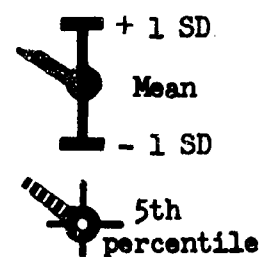
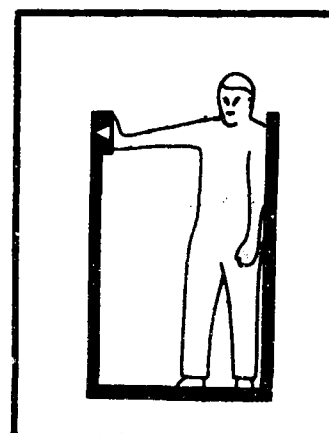
Trial No.	MAXIMAL STATIC PUSH FORCES				ADJUSTMENTS OF PUSH PANEL AND WALL					
	exerted horizontally on the push panel				HEIGHT of the center of the push panel			Horizontal DISTANCE between push panel and wall		
	Mean kp	SD kp	5th %	N	% of AH*	Mean cm	SD cm	% of LTR†	Mean cm	SD cm
8.1	29.1	3.4	1.1	42	100	145.9	4.6	50	54.4	1.9
8.2	34.5	10.0	18.8	44	100			60	65.3	2.4
8.3	55.3	18.3	33.5	44	100			70	76.2	2.8
8.4	76.0	19.4	44.4	43	100			80	87.0	3.3
8.5	62.2	21.4	32.3	43	100			90	98.0	3.7
8.6	26.9	11.6	8.7	38	100			100	108.9	4.0

*Acromial Height (Shoulder Height); see Appendix II.

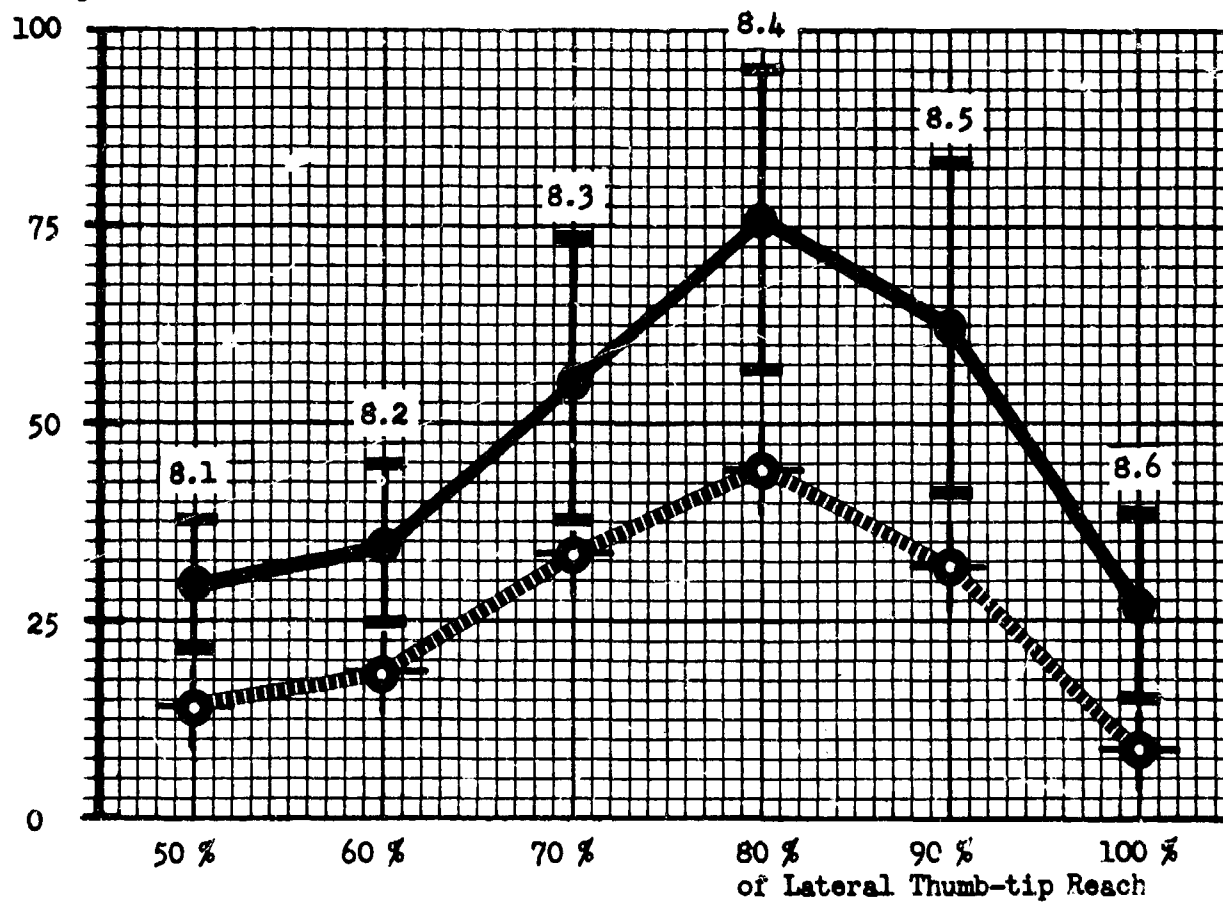
†Lateral Thumb-tip Reach; see Appendix II.

Figure 12. Results of experiment 8.

Experiment 8



FORCE
in kp



DISTANCE BETWEEN PUSH PANEL AND WALL

EXPERIMENT 8 — Comments

Body Position

At the closest adjustment between push panel and wall, the pushing arm had to be distinctly bent; the greater the distance, the more the pushing arm had to be extended. The farthest adjustment between push panel and wall caused the subjects to place their fingertips instead of their palms against the wall. Some subjects, however, could not reach the push panel at all if they kept one shoulder against the wall as required.

Forces

Statistics — The magnitude of the exerted forces is small to moderate, the spread of the means relatively large, falling between 27 and 76 kp. The statistical test of the differences between the means yielded the following results:

8.2	s				
8.3	s	s			
8.4	s	s	s		
8.5	s	s	s	s	
8.6	o	s	s	s	s
	8.1	8.2	8.3	8.4	8.5

o = Null hypothesis maintained.

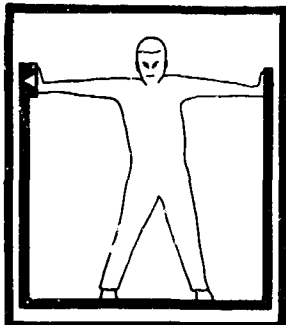
s = Null hypothesis rejected:
forces exerted at the two compared conditions are significantly different from each other.

Effects of Distance Adjustments — Both the closest and the farthest distance adjustments, corresponding respectively to half and to full Lateral Thumb-tip Reach, were about equally unfavorable for exertion of push forces. The closest adjustment required a severe bending of the pushing arm at the elbow with great mechanical disadvantage. The farthest adjustment forced the subjects to push with their fingertips instead of with the palm of their hand. Thus, the force registered at the push panel was not so much determined by the muscular strength, but by the tolerable thrust and pain in the fingers. Distance adjustments of between 70 and 90% of the individual's lateral Thumb-tip Reach allowed the most forceful pushes, exerted with the arm held more or less straight by attempted expansion of the shoulders or by a slight attempted rotation of the shoulder girth with regard to the lower part of the body.

Conclusion

Lateral push with one arm, the opposite shoulder against a wall, is very ineffective for mechanical reasons if the distance between push panel and wall is either 50, 60 or 100% of the Lateral Thumb-tip Reach. If the distance between push panel and wall is in the range from 70 through 90% of the lateral reach, force is exerted with the arm held straight and by attempted expansion or rotation of the shoulders. In this position, even weak operators (5th percentile) could exert at least 32 kp.

Experiment 9



LATERAL PUSH WITH ONE HAND

REACTION FORCE PROVIDED BY A VERTICAL WALL

The push is exerted with the preferred hand; the other hand is flat against the wall, the arm straight.

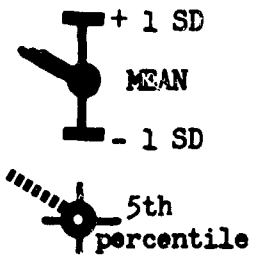
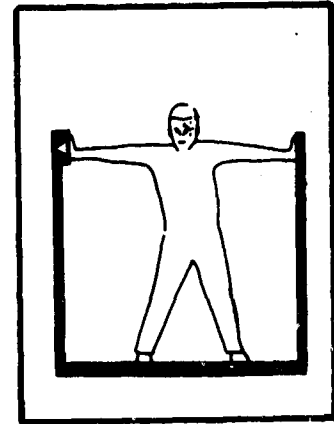
Trial No.	MAXIMAL STATIC PUSH FORCES exerted horizontally on the push panel				ADJUSTMENTS OF PUSH PANEL AND WALL					
	Mean kp	SD kp	5th %	N	HEIGHT of the center of the push panel			Horizontal DISTANCE between push panel and wall		
					% of AH*	Mean cm	SD cm	% of Span†	Mean cm	SD cm
9.1	37.4	13.9	16.9	30	100	145.9	4.6	50	92.1	3.2
9.2	35.3	12.7	19.1	41	100			60	110.5	3.8
9.3	52.9	16.7	27.7	41	100			70	129.0	4.5
9.4	72.1	19.4	43.7	42	100			80	147.4	5.1
9.5	33.1	13.5	14.7	37	100			90	165.7	5.7

*Acromial Height (Shoulder Height); see Appendix II.

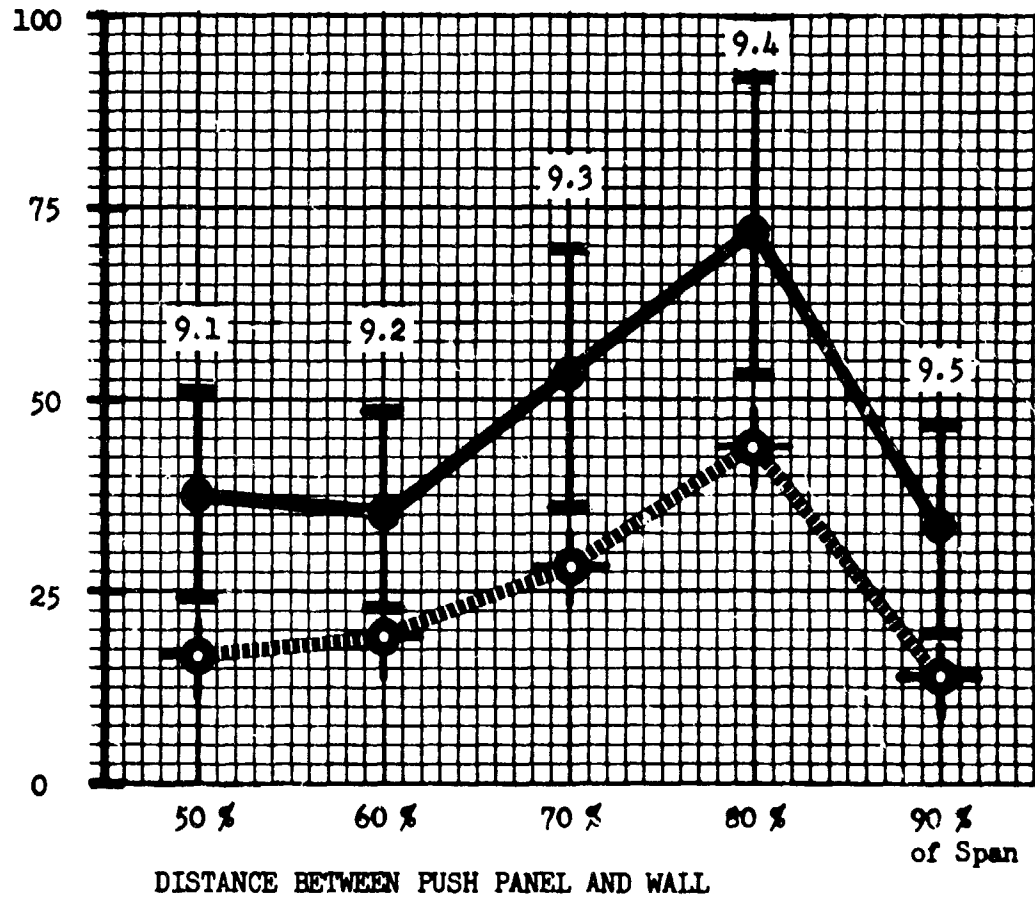
†See Appendix II.

Figure 13. Results of experiment 9.

Experiment 9



FORCE
in kp



EXPERIMENT 9 – Comments

Body Position

The subject had to keep his non-preferred arm straight and horizontally extended toward the wall. The other arm was more or less bent depending on the distance between wall and push panel. The smallest distance proved to be too small for some subjects, who could not keep one arm straight even when the other was totally bent. At the distance equaling total Span, the subjects had to apply force to the push panel with their fingers instead of using the palm of the hand.

Forces

Statistics – The magnitude of the exerted forces is small to moderate, the spread of the means is relatively large, the means falling between 33 and 72 kp. The statistical test of the differences between the means yielded the following results:

9.2	o				
9.3	s	s			
9.4	s	s	s		
9.5	o	o	s	s	
	9.1	9.2	9.3	9.4	9.5

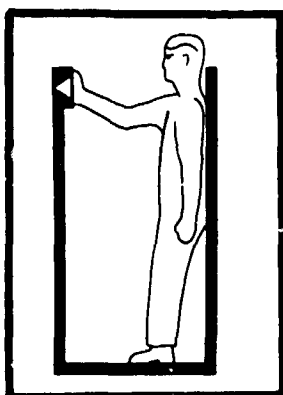
o = Null hypothesis maintained.
s = Null hypothesis rejected: forces exerted at the two compared conditions are significantly different from each other.

Effects of the Distance Arrangements – Short distances between push panel and wall (equaling 50 to 60% of the individual Span) as well as the longest distance (100% of Span), provided a rather unfavorable condition for force exertion. The narrow space forced the subjects to push at the push panel with a severely bent arm with great mechanical disadvantage. The farthest adjustment used was in fact too great to allow force exertion with the palm of the hand against the push panel; thus, the force had to be applied with the finger tips. In this position, the obtained scores represent not so much the muscle strength of the subjects but the stress and pain they were willing to tolerate in their fingers. At distances corresponding to 70 or 80% of the individual Span, moderately large forces could be exerted. The 70% distance caused only slight bending of the pushing arm, while at 80% the subjects could wedge themselves between wall and push panel with both arms held straight.

Conclusion

Within the experimental limitations, both the shortest and the longest adjustments of the distance between push panel and wall were about equally unsuitable for force exertion in the prescribed way, since the operator was forced to exert force with great mechanical disadvantage. If the distance between push panel and wall was set to 70% or, better, to 80% of Span, moderate force could be exerted by the subject with his arms locked straight between the opposing surfaces; weak subjects (5th percentile) could exert between 28 and 44 kp.

Experiment 10



FORWARD PUSH WITH ONE HAND

REACTION FORCE PROVIDED BY A VERTICAL WALL

The push is exerted with the preferred hand. Both shoulders must touch the wall.

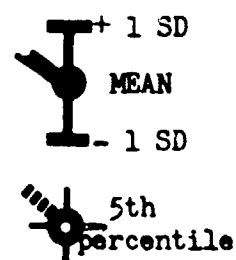
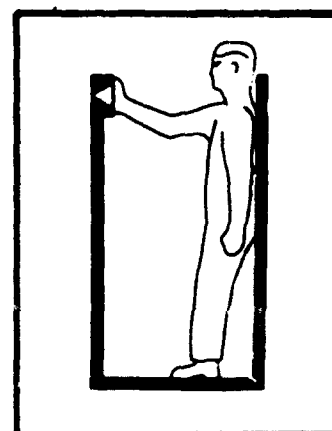
Trial No.	MAXIMAL STATIC PUSH FORCES				ADJUSTMENTS OF PUSH PANEL AND WALL					
	exerted horizontally on the push panel				HEIGHT of the center of the push panel			Horizontal DISTANCE between push panel and wall		
	Mean kp	SD kp	5th %	N	% of AH*	Mean cm	SD cm	% of TR†	Mean cm	SD cm
10.1	26.8	6.6	14.9	39	100	145.9	4.6	50	41.0	2.2
10.2	30.3	7.2	16.0	40	100			60	49.3	2.6
10.3	36.9	9.8	21.8	39	100			70	57.5	3.1
10.4	53.1	14.6	29.4	40	100			80	65.7	3.5
10.5	50.3	17.4	24.7	40	100			90	74.0	4.0
10.6	43.7	17.8	19.3	35	100			100	82.2	4.4

*Acromial Height (Shoulder Height); see Appendix II.

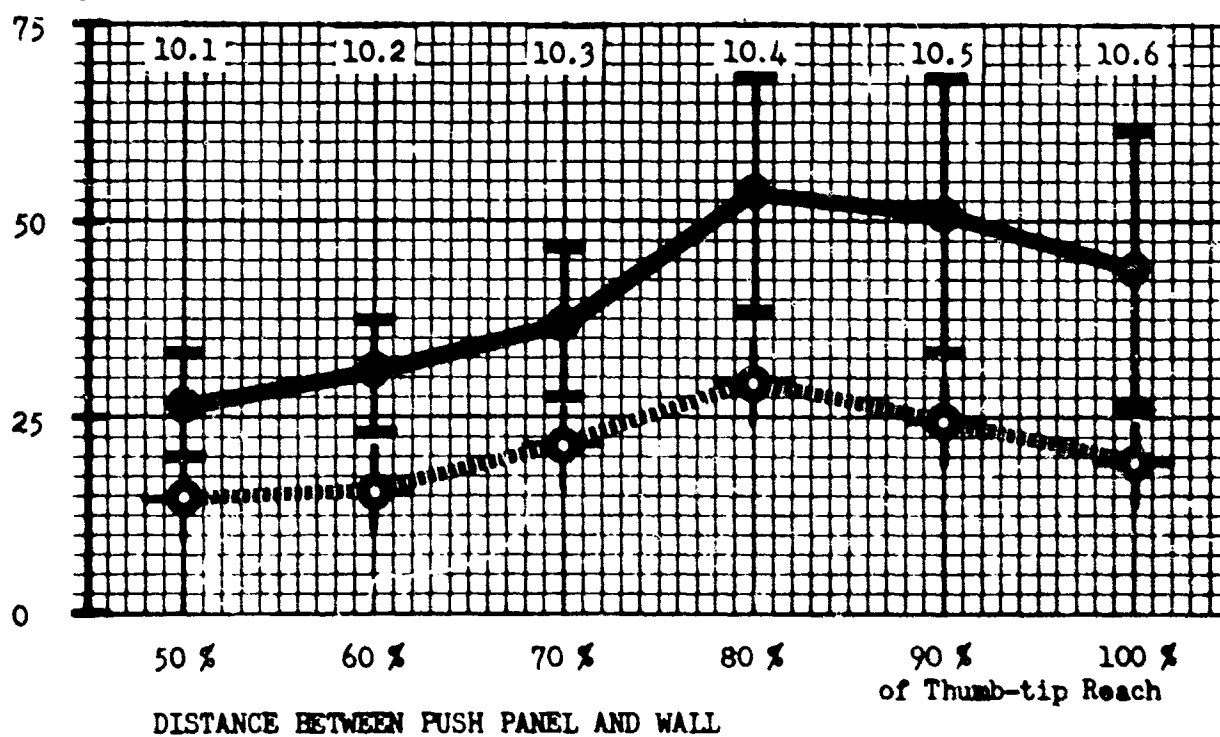
†Thumb-tip Reach; see Appendix II.

Figure 14. Results of experiment 10.

Experiment 10



FORCE
in kp



Body Posture

Forces

10.2	s				
10.3	s	s			
10.4	s	s	s		
10.5	s	s	s	o	
10.6	s	s	s	s	s
	10.1	10.2	10.3	10.4	10.5

o = Null hypothesis maintained
s = Null hypothesis rejected: forces exerted at the two compared conditions are significantly different from each other.

Conclusion

50

Section VII

DISCUSSION OF THE RESULTS

In the following, the results of the experiments are discussed in relation to the magnitude of forces exorable while the subject is either free standing on the floor or braced against a vertical wall, and to the amount of force exerted while pushing either with one hand only or with both hands or the shoulders or the back.

COMPARISON WITH OTHER EXPERIMENTS

As stated in the introduction, only very few studies have been published that deal with the problem of human strength exorable under realistic, every-day conditions. Among the rare exceptions are Dempster's studies (1955, 1958, 1961), in which pulling subjects braced themselves against a footrest while positioning their bodies so as to make greatest possible use of their body mass as a source of reaction force to the pulls actively exerted. Still, Dempster's investigations on pull capacities do not allow any detailed comparisons with our study on push forces.

Not comparable at all are the many studies on static strength of seated operators. The effects of body mass, of the use of rigid surfaces to brace against (Caldwell 1959a, 1960, 1962), generally, the effects of the flow of force vectors through the body of the subject are very different in the standing and in the sitting position.

Even most of the studies on standing subjects cannot be used for comparison, since they normally were required to maintain an erect body position and could not brace themselves while exerting forces. Under these conditions, the push force is limited by the resistance the body has against being tilted over, as Rohmert (1960a) pointed out. This also explains, at least partly, Konz' and Day's findings (1966).

Comparable to our study are the experiments conducted by Streimer and Springer (1963), and by W. F. Fox (1967). Streimer and Springer adjusted a horizontal bar at "knee height," "waist height," "chest height" and "overhead," respectively, and asked their subjects (45 male college students) to exert their maximum isometric push force horizontally in a single effort. No restrictions were imposed on the subjects with respect to the postural positions they assumed, since it was postulated that given free choice, the subjects would position themselves in the most adequate and comfortable manner. Unfortunately, the form of the push bar was not described. Not mentioned either was the type of footwear the subjects used, nor the kind of floor surface or floor material on which they stood.

For the two-handed and the one-handed pushes, Streimer and Springer tabulated the following results (in lb):

<i>Height of the Push Bar</i>	<i>Force Exerted With Two Hands</i>		<i>Force Exerted With One Hand</i>	
	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>
Knee Height	105.9	18	82.0	20
Waist Height	113.9	21	75.1	18
Chest Height	92.8	19	73.0	23
Overhead	58.5	14	53.1	13

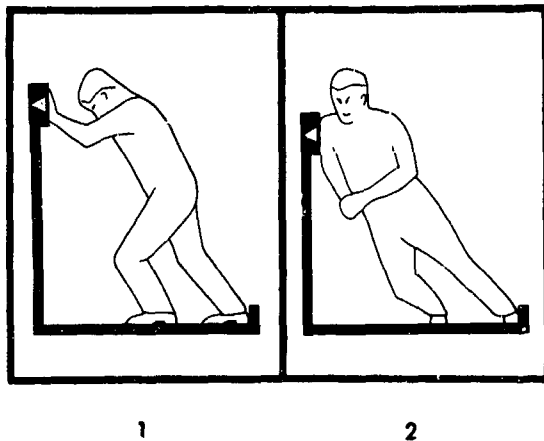
It is rather difficult to compare these data with ours since: (a) the amount of reaction force available to the subjects at their feet was very different in the two experiments (limited but unknown versus infinite in our experiments); and (b) Streimer and Springer did not define what they measured as "maximal forces" (it could be "peak" forces as well as "mean" forces), finally, (c) the subject populations as well as the experimental conditions may be different. In general, however, the results of the two studies seem not to be in disagreement with each other.

W. F. Fox (1967) used a horizontal bar, 2 inches high, raised 24 inches above the floor and a large vertical plywood board, located above the bar. Against the bar or the board, maximal isometric push forces were exerted. The subjects either placed both hands against the vertical surfaces while pushing forward, or pushed laterally with one shoulder against the board, or pushed backward. In one part of the experiments, the subjects (52 males, most between 21 and 50 years of age) could anchor their feet against the rungs of a wooden ladder lying on the floor. (The rungs were about one inch in diameter, spaced 13 inches apart.) The subjects, free to assume the most appropriate body position, exerted the following average forces (in lb; Fox used approximately the same definition for "maximal force" as we did).

	<u>Mean</u>	<u>SD</u>
Forward push at the board exerted with both hands	214.5	66.1
Forward push at the bar, exerted with both hands	202.9	60.2
Lateral push at the board, exerted with one shoulder	225.7	82.9
Backward push	272.7	67.3

Fox's first two conditions can be compared roughly with those in our experiment 1; Fox's mean values are larger than our highest averages. The lateral shoulder push is comparable to our experiment 2; Fox's data approximate our results. Fox's back push conditions may, with caution, be compared with those in our experiment 6; our data are substantially higher. In our backward pushes, the subjects braced themselves against a vertical wall, while in Fox's experiments, the subjects had a "non-slip floor" (i.e., they anchored their feet on the rungs of the ladder). This is likely to cause different body postures and consequently, differences in recorded forces. Differences in design and arrangement of the push panels in Fox's and our experiments may, among other reasons, account for the discrepancies in the forces exerted in the forward pushes. In general, however, the similarity of Fox's and our data is obvious.

OPERATOR FREE STANDING (EXPERIMENTS 1 AND 2)



In both experiments, the subjects pushed horizontally while free standing, using as a body brace only the footrest, which prevented their shoes from sliding backward on the floor. The basic difference between the experiments was that push was exerted in experiment 1 with the hands and in experiment 2 with one shoulder.

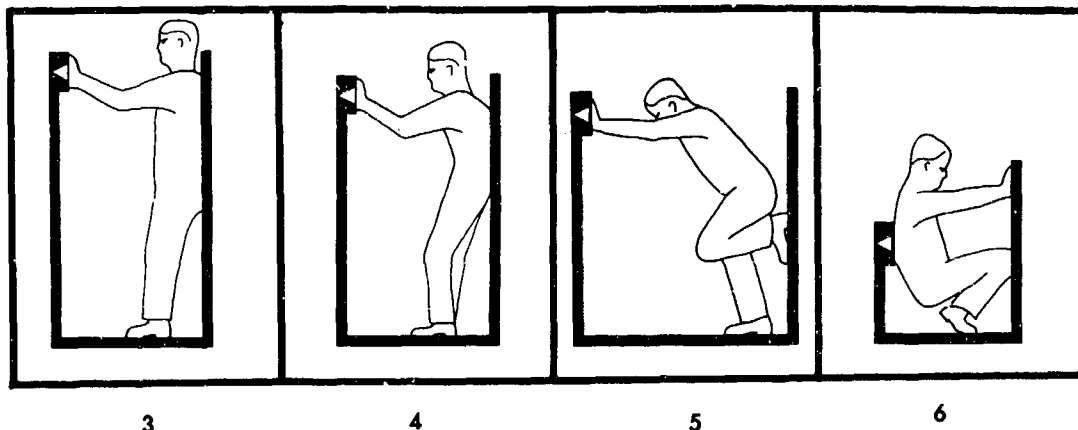
The patterns of the results obtained in both experiments are very similar (see figures 5 and 6, pages 12 and 16). The more diagonally the subject could lean against the push panel, the better he could wedge his body between the panel and the footrest, and the larger the forces he could apply to the push panel. The magnitude of the forces exerted in the two sets of experiments, however, are distinctly different from each other. Pushing forward with both hands is generally less efficient than pushing laterally with the preferred shoulder. This becomes quite obvious when the exerted forces are tabulated according to directly comparable conditions in which the same height and distance adjustments of the push panel are used:

<u>Trial Number</u>	<u>Mean Force in kp</u>
1.4 versus 2.2	56 versus 63
1.5 versus 2.3	55 versus 65
1.7 versus 2.5	64 versus 71
1.8 versus 2.6	70 versus 74

The null-hypothesis may be maintained (t-test) only for the last pair of data. This constitutes the very best experimental condition for forward push with both hands, while considerably larger forces than even 74 kp can be exerted with the shoulders under other conditions (trials 2.7, 2.8, 2.9, page 16).

In the first experiment, hands and arms are apparently the weak links in the chain of body parts transmitting force from the push panel to the floor through the body. In the second experiment, the flow of force vectors is through shoulders, trunk and legs only, omitting the relatively weak arms and hands; therefore, the shoulder pushes are generally stronger than the hand pushes.

**OPERATOR BRACED, PUSHING FORWARD WITH BOTH HANDS OR BACKWARD
(EXPERIMENTS 3, 4, 5, AND 6)**



In these experiments, the subjects were provided a vertical wall against which to brace themselves during exertion of pushes. In experiments 3 and 4, they had their backs against the wall, standing more or less upright and pushing at about shoulder height. In experiment 5, the subjects had to lean forward to push, keeping one foot flat against the wall. In all these experiments, the subjects had to push forward, but in experiment 6 they pushed backwards, bracing their hands or knees or feet against the supporting wall.

To facilitate comparisons of the results, experiments 3, 4, and 6 were planned so that the distance adjustments would overlap; adjacent distance adjustments were used in experiment 5.

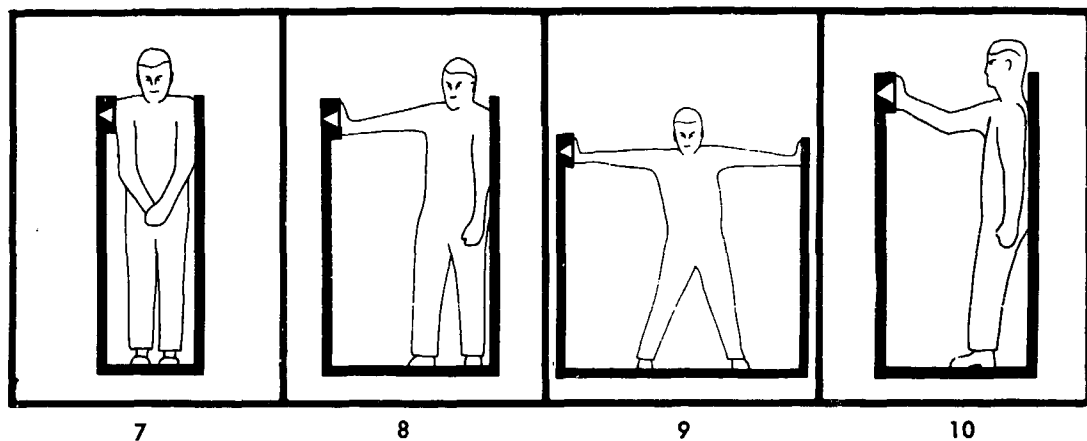
In experiments 3 and 4, the subjects exerted force in similar ways; therefore, the general pattern of results and the magnitude of the exerted forces are very much alike. In fact, by putting the graphs (figures 8 and 9, pages 24 and 28) side by side with the necessary overlap, the curve of experiment 4 can be used as the extension of the curve of experiment 3. When pushing at about shoulder height and standing within a narrow space between push panel and wall, only relatively small forces can be exerted with bent arms. If the parallel surfaces are moved far enough apart to allow the subject to push with his arms straight and his back against the wall, he can exert rather large forces. A greater distance between the wall and push panel causes the subject either to push with his fingertips, while keeping his back against the wall, or to lean forward from the wall. Both ways of force exertion are rather ineffective.

An even greater increase in the distance between push panel and wall was investigated in experiment 5 (figure 9, page 28). To reach the push panel with both hands, the subject had to lean forward, pressing one foot against the wall behind him. The mean forces exerted in this posture show some variations with height and distance adjustment, but have the same magnitude as those exerted with the back against the wall (though not quite reaching the peak forces applied with stiff arms wedged between push panel and wall).

The 5th percentile force is remarkably constant in all three experiments: starting from 30 kp at the very closest distance between push panel and wall, it rises to over 50 kp if the distance is enlarged only a little, and then stays close to 50 kp with ever increasing distance. (Taking into account, of course, the best score if the subjects pushed at the same distance in different body positions.)

Experiment 6 (figure 10, page 32) shows that pushing backward with hands, knees or feet braced against a rigid surface is generally much more effective than any forward push; this is a common experience, confirmed in this study. The mean as well as the 5th percentile forces of the backward pushes are without exception considerably higher than any of the forward pushes. The 5th percentile force never falls below 70 kp, it even stays above 100 kp as long as the subject can wedge himself between the parallel surfaces with his legs extended. While comparing the results of experiments 3, 4 and 5 with those of experiment 6, it should be kept in mind that, (a) backward pushes as in experiment 6 require that the surface pushed against be rather low, and that (b) the range of possible distance adjustments between push panel and the wall to brace against is rather limited for back pushes. Forward pushes with the hands can be exerted at much higher and at much more distant push panels than back pushes.

**OPERATOR BRACED, PUSHING WITH ONE SHOULDER OR WITH ONE HAND
(EXPERIMENTS 7, 8, 9, AND 10)**



In experiments 7 through 10, forces were exerted with either one hand or with one shoulder, respectively. The distance between push panel and wall was very short in experiment 7, so that the subject had to wedge his shoulders between the two surfaces; the distance was gradually increased in experiment 8 so that the subject could push laterally with one hand, holding his opposite shoulder against the wall. In experiment 9, the wall was moved out even more until the subject had to extend both arms laterally to touch the wall with one hand and the push panel with the other hand.

Wedging the shoulders between narrowly spaced surfaces, as in experiment 7 (figure 11, page 36), is effective only if the space is distinctly less than shoulder breadth; this is a rather uncomfortable position. Increasing the distance up to shoulder width resulted in an almost complete loss of the ability to apply force in this way. In general, this way of force application appears to be effective only under exceptional circumstances and, therefore, impractical.

Pushing with the preferred hand and keeping either the opposite shoulder (experiment 8, figure 12, page 40) or the other hand (experiment 9, figure 13, page 44) against the wall is rather ineffective if the pushing arm must be severely bent; the more it can be extended, the better the subject can wedge himself between push panel and wall. If the space between the opposing surfaces is too wide, the subject has to push with his fingertips instead of with the palm of his hand, which leads to a drastic reduction of applicable push force.

Overlapping distance adjustments in experiments 8 and 9 allow superimposition of the force curves of each experiment. The curves, both of the mean and 5th percentile forces, show great fluctuation. The scores are low at short distance between push panel and wall (pushing arm bent). A first maximum is reached at moderate distance (arm straight, shoulder against the wall); at only slightly increased distances, the curves fall to a relative minimum (fingertip push or bent arm, respectively). A second relative maximum appears at large distance (both arms straight) followed again by a sharp decline at further increased distance, where it becomes more and more difficult to reach both surfaces at all.

In experiment 10 (figure 14, page 48), the subject pushed forward with the preferred arm, keeping his back against the supporting wall, the push panel placed at given fractions of the forward reach capability. This is basically the same as in experiment 8, where lateral push was exerted. It is, therefore, not surprising to find the same pattern of results in both studies. Little force is exorable with bent arms if the distance is short between push panel and wall; improvement occurs with increasing distance, a maximum is reached with straight arms, then the force decreases with further increase of the distance between push panel and wall. At the closer adjustments of the wall, lateral and sagittal push are about equally effective, but the maximum of the lateral push (with straight arm) is somewhat higher. Here, the muscles of the trunk and the legs can be used to twist the trunk and so to wedge the shoulder and arm between push panel and wall.

In conclusion: The horizontal push forces that can be exerted with one hand — laterally or sagittally — against a push panel while bracing the body against an opposite wall depend in a rather irregular way on the spacing between push panel and wall; in any case, these forces are rather small, the 5th percentile values being between 15 and 44 kp.

OPERATOR BRACED, PUSHING EITHER WITH ONE HAND OR WITH BOTH HANDS

Experiments 3 and 10 can be compared directly with each other: in both, the same height and distance adjustments were used. The push panel, fixed at shoulder height, was adjusted between half and full (thumb-tip) forward reach in 10% increments from the wall. In experiment 3, the subjects pushed forward with both arms; in experiment 10 they used only the preferred hand.

The pushes exerted with both hands (figure 7) are considerably stronger than those exerted with one hand (figure 14). This holds true even for the weakest two-hand push as compared to the strongest one-hand push. (The differences between the means were found to be highly significant in the t-test.) At the same distance adjustments, the forces transmitted with both arms are roughly about double as large as those transmitted with one arm.

For a general survey, the following list of forces exerted while braced at the vertical wall may be used:

<u>Two-Handed Pushes</u>	<u>Range of Mean Forces (in kp)</u>
Experiment 3, page 20	60-131
Experiment 4, page 24	77-112
Experiment 5, page 28	64- 88
<u>One-Handed Pushes</u>	
Experiment 8, page 40	29-76
Experiment 9, page 44	35-72
Experiment 10, page 48	27-53

Although only experiments 3 and 10 can be compared directly, it is quite obvious that force exertion with only one arm is generally much less effective than pushing with two arms. When comparing the most favorable conditions one one-handed pushes with the most unfavorable circumstances for two-handed pushes, the largest forces exerted with one hand just reach the level of the weakest pushes applied with two hands.

FORCES EXERTABLE FREE STANDING VERSUS BRACED

In pilot studies, short as well as long distances between the push panel and the footrest were found to be disadvantageous for exerting push forces while free standing. Therefore, only horizontal distances in the range from 87 cm to 131 cm were used in experiments 1 and 2, allowing effective pushes. The mean forces that could be exerted under these "ideal" conditions lie between 44 and 87 kp (figures 5 and 6, pages 12 and 16).

A wide range of distance arrangements, however, could be used in the experiments with the vertical wall against which the subjects braced themselves: the smallest mean distance was 39 cm (experiment 7), the largest 175 cm (experiment 5). At any given distance in this range, the braced subjects could exert at least the same and often much larger forces than those exerted while free standing. (See figures 7 through 14, pages 20 through 48). This fact alone leads to the conclusion that braced force exertion is preferable to free standing pushes.

There is, however, a second important point in favor of braced force exertion. In free standing experiments, the subjects could place one foot against a footrest, which gave them a perfect hold on the floor. In "real world" situations, such "infinite friction" between the footwear and the floor often does not exist. Normally, the operator finds only limited traction on the ground, the magnitude of which depends on the shape and the material of floor and shoes, and on lubricants between them. Under conditions of finite friction, i.e., limited reaction force available, the operator would slide on the ground if trying to exert very large push forces. Such sliding would reduce the exerable push force to values even below those measured in our "ideal" experiments 1 and 2.

No operator can exert larger forces than the reaction forces available to him. For the free standing operator, this reaction force depends on two factors: on the coefficient of friction between his shoes and the floor and on the force he transmits from his shoes to the ground in a direction perpendicular to the contacting surfaces. Only some preliminary data on coefficients of friction between different shoe and floor materials have been measured (Fox, 1967); additional data are necessary.

An analysis of our data revealed that the weight of the subject does not seem to play a very important role with respect to the amount of force exerted. This is not so surprising if the body is held upright (as in experiments 3, 4, 7, 8, 9 and 10), since under those conditions the center of gravity of the subject's body is above his feet. However, if he is leaning towards the dynamometer (as in experiments 1, 2 and 5) the center of gravity of his body falls in front of his feet. This creates a torque that pushes his body towards the push panel. Thus, his weight causes some push force by itself. It seems, however, that the force actively exerted by contracting muscles outplays the effect of the subject's weight with respect to the push force recorded on the dynamometer. Studies are being conducted to investigate the relative effects of muscle strength, weight and friction.

Until additional studies are finished, it is impossible to predict the push forces exerable by subjects standing on a "slippery" ground (Fox, 1967). It is clear, however, that such forces will be smaller than those that can be exerted while standing on non-slip floors, as in experiments 1 and 2 (figures 5 and 6, pages 12 and 16).

MINIMUM FORCES

Average forces generally cannot serve as a design basis. If a mean push force were used to determine, for example, the mass of a piece of equipment that must be pushed by man, then about half of the personnel, the weaker half, could not move this object. To exclude so many people is intolerable; only the very weak may be disregarded. The 5th percentile force is generally accepted as the threshold value for design purposes.

Using the 5th percentile forces, general rules can be established with regard to the horizontal push forces that may be exerted statically by any population for which our subjects are representative, and under conditions similar to those in our experiments.

The operator must be free to select (by experience or trial) the most appropriate body position and the most advantageous way of exerting force; hence, the general rules are based on the best rather than on all experimental results. The operator's choice of the most effective manner of force exertion must not be restricted by size and location of the push panel at which he exerts force; it should be adequately designed and positioned.

A very small or badly located push panel might allow only one-hand pushes as in experiments 8, 9, and 10. Figure 15 shows the best three mean scores of each of these experiments and the three highest 5th percentile forces, plotted over the distance between push panel and the opposing surface against which the subjects braced themselves. As the graph shows, the critical 5th percentile forces rarely fall below 25 kp. For all distances between about 50 and 150 cm, 25 kp may be assumed as the minimum push force which can be exerted with one hand. This rather poor result indicates how relatively ineffective pushes with one hand are, even if body stabilization is provided by a vertical wall and if the push panel is adjusted to the most convenient height above the floor, i.e., to just below shoulder level.

Much more effective are pushes exerted with both hands while leaning against a vertical wall, as performed in experiments 3, 4, and 5. The three largest mean scores and 5th percentile forces of each of these experiments are plotted in figure 16 over the space between push panel and opposing vertical surface. This figure also contains the relevant results of experiments 1 and 2, in which the subjects stood on a perfectly non-slip floor, pushing either with both hands or with the preferred shoulder. Regardless of distance or manner of body stabilization, the critical 5th percentile forces cluster close to 50 kp. For all pushes exerted either with both hands or with the shoulder, 50 kp may be assumed to be the minimum push force that can be exerted either while standing on a non-slip floor or while bracing the body against a vertical surface. To allow selection of the most appropriate body position, the push panel should be about as wide as the shoulders and extend vertically from hip to shoulder level.

The most effective way to exert horizontal force is to push backward against a very low board, placing the hands, and/or knees, and/or feet against a vertical surface (experiment 6). This body position allows exertion of from 72 to 93 kp if the distance between push panel and opposing surface is between about 60 and 85 cm; at larger distances (up to about 110 cm), more than 100 kp can be exerted. Fox's experiments (1967) offer some information on the effectiveness of back pushes when reaction force is provided to the subject by a perfectly non-slip floor. About 75 kp is the 5th percentile force, which can be calculated from his data (mean minus 1.65 standard deviations). This is very close to the lowest 5th percentile forces measured in our experiments. Therefore, it may be assumed that in back pushes at least 75 kp can be exerted, regardless of whether a vertical wall or a non-slip floor provide reaction force.

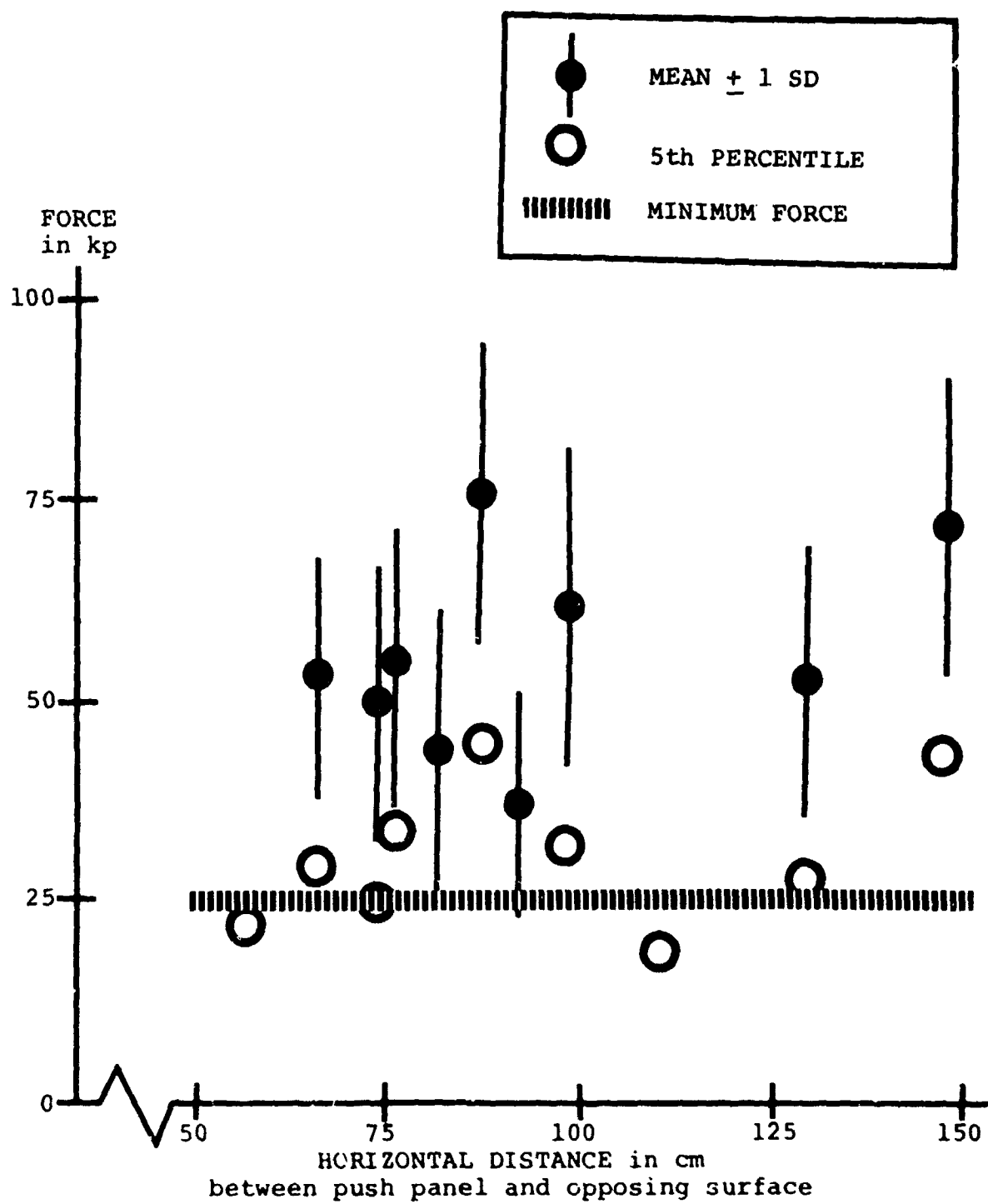


Figure 13. Forces exerted with the preferred hand.

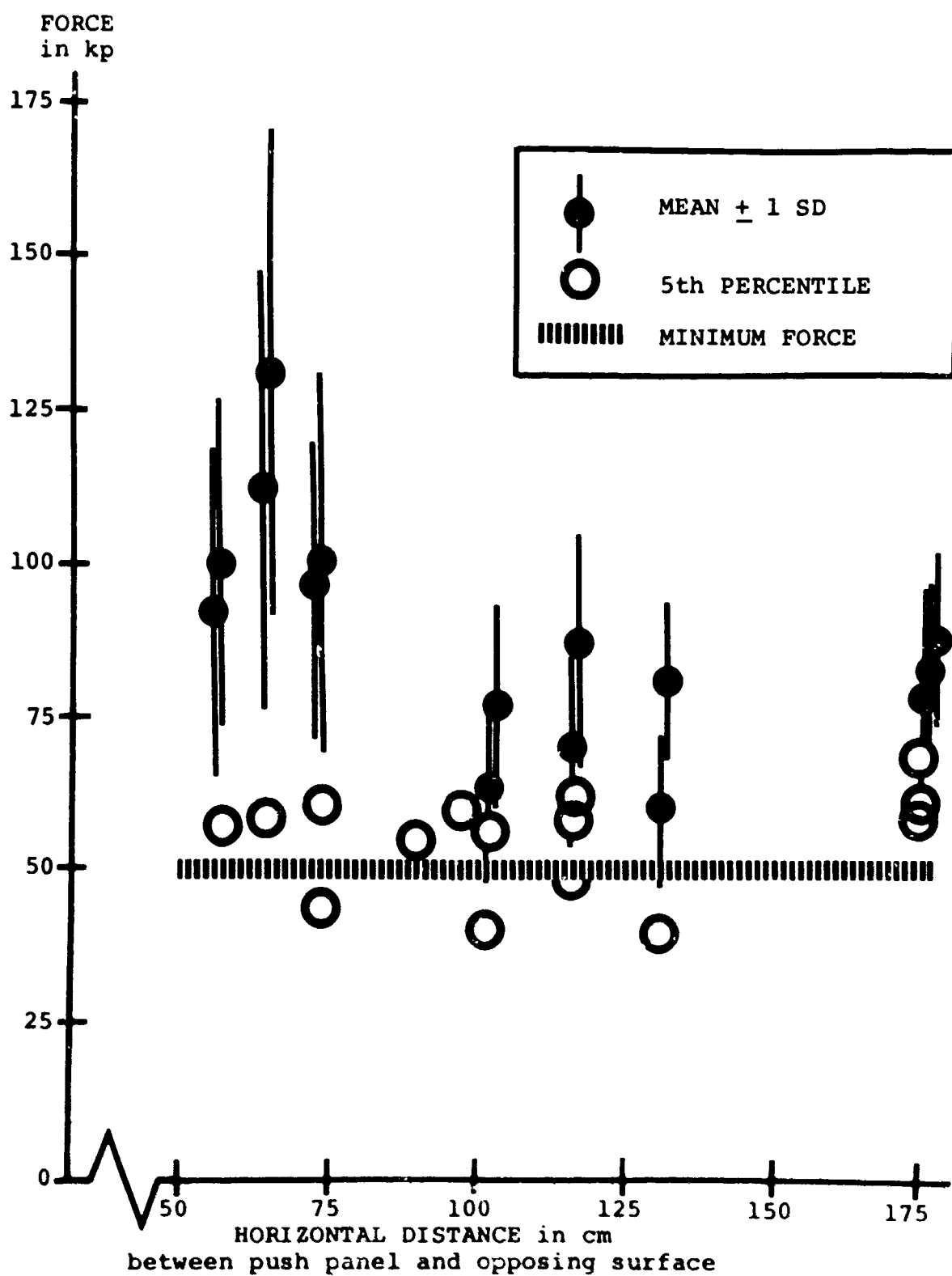


Figure 16. Forces exerted with both hands or with the preferred shoulder.

Section VIII

SUMMARY AND CONCLUSIONS

Forty-five male subjects assumed 65 different body postures. In each position, they exerted their maximal isometric force while pushing horizontally forward, laterally, or backward. They pushed with one hand, or both hands, or one shoulder, or with their backs, while either anchoring their feet at a footrest on the floor, or while bracing themselves against a vertical wall.

Somewhat simplified, the experimental results may be summarized as follows.

- Large horizontal static push forces are exerable if the operator can wedge his body between the vertical surfaces of the push panel and the opposing wall, and if the flow of force vectors through his body is about horizontal.

The highest forces can be exerted when pushing backwards (experiment 6) with the lower part of the back against the push panel, both feet against the wall, and the legs almost completely extended. If the space is narrow, it is almost as effective to place knees and hands against the wall.

Rather high force can be applied by wedging both shoulders between the wall and push panel (experiment 7). Unfortunately, the distance between the wall and panel must be adjusted to a very uncomfortable 80% of the operator's shoulder breadth to enable him to push effectively.

Keeping both shoulders against the wall and wedging oneself with both arms held straight and forward between wall and push panel is also rather efficient (experiments 3 and 4); at short distances, however, the arms have to be bent, which reduces the exerable force considerably.

- Only relatively small horizontal push forces can be exerted if the flow of force vectors from the push panel through the operator's body to the supporting surface is distinctly oblique, or if force is exerted with one arm only.

Placing one foot against a footrest on the floor and pushing laterally with the preferred shoulder is slightly more effective than pushing forward with both hands, either with one foot placed against a wall or anchored at a footrest on the floor (experiments 2, 5 and 1). In the shoulder push, the flow of force is through the strong trunk and legs only, while in the forward pushes force must be applied with the arms, which are relatively weak.

Pressing with only one hand results in weak pushes, even if the operator can brace himself against a vertical wall (experiment 10 as compared with experiment 3). Whether the push is exerted laterally (experiments 8 and 9) or forward (experiment 10) does not make much difference with regard to the magnitude of force. If the distance between wall and push panel is either larger or smaller than 80% of the respective reach capability, only very weak pushes can be exerted.

A note of caution seems appropriate about the applicability of the experimental data.

Data on human force capabilities, as presented in this report and as often found in human engineering handbooks, are concerned with static muscle strength.

Static, or isometric, force is being exerted if a muscle contracts but does not change its length during contraction. Dynamic work (which, of course, also includes force exertion) is performed by alternative contractions and relaxations of muscles, during which their lengths change. In static control operation, for example, application of static force means that the operator holds the control in place or applies a "break-away" force while neither he nor the control actually move. During dynamic operation, however, the operator always moves the control with regard to his body, this motion of the control being effected or at least accompanied by exertion of dynamic energy.

Although muscular efforts are involved both in exertion of static strength and in dynamic work, one can not be predicted accurately from the other, and training of one may not much affect the other as discussed by Asmussen, Hansen, and Lammert, 1965; Ball, Rich, and Wallis, 1964; Bender and Kaplan, 1966; Berger, 1962, 1963; Berger and Henderson, 1966; Chui, 1964; Clarke, 1962, 1968; Colgate, 1966; Dern, Leverne, and Blair, 1947; Gentry and Randall, 1966; Harrison, 1963; Hunsicker, 1955; Ikai and Steinhaus, 1961; Kogi, Mueller, and Rohmert, 1965; Kroemer, 1967b, 1969; Martens and Sharkey, 1966; Mueller, 1962, 1964; Pearson, McGinley and Butzel, 1963; Petersen, 1962; Rasch and Pierson, 1963; Singh and Karpovich, 1966; Smith, 1964, and Tornvall, 1963.

Data on static force capabilities should not be used for equipment evaluation if dynamic work is to be performed by the operator.

- Keeping the limitations of the reported data in mind, the following rules of thumb may be used to estimate the magnitude of static (isometric) push forces which can be exerted horizontally:

- (a) At least 25 kp (55 lb)* may be exerted with one hand if the operator can brace himself against a vertical wall located 50 to 150 cm (20 - 60 in.) from the push panel.

- (b) At least 50 kp (110 lb) may be applied with both hands or with the shoulder if the operator can brace himself against a vertical wall 50 to 175 cm (20 - 70 in.) from the push panel, or if a non-slip floor is available to him.

- (c) At least 75 kp (165 lb) may be exerted in backpush if the operator can brace himself against a vertical wall located 60 to 110 cm (23 - 43 in.) from the push panel, or if a non-slip floor is available to him.

- (d) Exertion of these push forces requires a suitable push panel. Its surface should be vertical and large enough to allow force application either with the hands, the shoulder, or the back. It should be about 40 cm (16 in.) wide, start at approximately 50 cm (20 in.) and end at about 125 cm (50 in.) above the floor. The surface of the panel should be rough enough to provide a large coefficient of friction.

*Since the values are only estimates, they are rounded to convenient numbers.

Appendix I

SAMPLE DATA BLANK

ANTHROPOMETRIC DATA OF THE SUBJECTS

Measured by Date Subject No.

Name Age yrs. righthanded ()
nearest birthday lefthanded ()

MARK: Acromion r, Biceps r & l, Tibiale r, Calf r & l

Subject Standing

1. Weight kg
2. Grip Strength I kp
3. Stature cm
4. Acromial Height cm
5. Tibiale Height cm
6. Biceps Circumference, right
Flexed cm
Relaxed cm
7. Biceps Circumference, left
Flexed cm
Relaxed cm
8. Upper Thigh C., right cm
9. Lower Thigh C., left cm
10. Calf Circ., right cm
11. Calf Circ., left cm
12. Grip Strength II kp
13. Lateral Thumb-tip Reach cm

14. Thumb-tip Reach cm

15. Span cm

16. Humeral Breadth, right cm

17. Humeral Breadth, left cm

Subject Sitting

18. Femoral Breadth, right cm
19. Femoral Breadth, left cm
20. Sitting Height cm
21. Knee Height, right cm
22. Bideloid Breadth cm
23. Buttock-Knee Length, right cm

Subject Standing

Skinfolds:

24. Triceps cm
25. Juxtanipple cm
26. Subscapula cm
27. Grip Strength III kp

Appendix II

DEFINITIONS OF ANTHROPOMETRIC MEASUREMENTS

The following definitions of the anthropometric measurements appear in the same order and numbered as in Sample Data Blank (Appendix I). The definitions rely heavily on those used by Hertzberg, et al. (1954, 1963) and by Clauser, et al.* Generally they comply with the rules recommended by the 1967 Conference on Standardization of Anthropometric Techniques and Terminology (Hertzberg, 1968).

1. *Weight* – The subject is nude or wears undershorts. The scale is read to the nearest half kilogram.

2. *Grip Strength I* – Subject stands relaxed. Subject is instructed to place Smedley dynamometer in his preferred hand, adjust the grip width to suit himself and squeeze the dynamometer as hard as possible. The scale is read to the nearest half kilopond.

3. *Stature* – Subject stands erect looking directly forward (head oriented in the Frankfort plane). With the anthropometer arm firmly touching the scalp measure the vertical distance from the standing surface to the top of the head.

4. *Acromial Height* – Subject stands erect. Using the anthropometer, measure the vertical distance from the standing surface to the most lateral margin of the right acromial process.

5. *Tibiale Height* – Subject stands erect. Using the anthropometer, measure the vertical distance from the standing surface to the medial margin of the head of the right tibia.

6. *Biceps Circumference, Right*

Flexed: Subject stands, supinates his forearm, makes a fist, and bends the elbow about 90 degrees while holding his upper arm horizontally. Holding the tape perpendicular to the long axis of the upper arm, measure the circumference of the arm at the level of the greatest anterior protrusion of the biceps.

Relaxed: Subject stands, his arm relaxed at his side. Holding the tape perpendicular to the long axis of the upper arm, measure the circumference of the arm at the level where Flexed Biceps Circumference is measured.

7. *Biceps Circumference, Left*

Flexed: Same as for Biceps Circumference, Right – Flexed, Item 6.

Relaxed: Same as for Biceps Circumference, Right – Relaxed, Item 6.

8. *Upper Thigh Circumference:* Subject stands with his legs slightly apart. Holding the tape in a plane perpendicular to the long axis of the thigh, measure the circumference of the right thigh at the level of the gluteal furrow.

9. *Lower Thigh Circumference:* Subject stands. Holding the tape in a horizontal plane, measure the circumference of the right thigh at the inferior margin of the relaxed lateral vastus muscle.

10. *Calf Circumference, Right:* Subject stands. Holding the tape in a horizontal plane, measure the maximum circumference of the calf.

11. *Calf Circumference, Left:* Same as for Calf Circumference, Right, Item 10.

*Anthropometry of Air Force Rated Officers – 1967. Technical Report in preparation.

12. *Grip Strength II*: Same as Grip Strength I, Item 2.

13. *Lateral Thumb-tip Reach*: Subject stands erect with his side toward a vertical surface, his shoulder touching the wall. His preferred arm is extended laterally and perpendicular to the vertical surface, the tip of his index finger touching the tip of the extended thumb, the thumb in the plane of the extended arm. Using the anthropometer, measure the horizontal distance from the vertical surface to the tip of the thumb.

14. *Thumb-tip Reach*: Subject stands erect with heels, buttocks, shoulder blades and head in contact with a vertical surface. His preferred arm is extended forward and perpendicular to the vertical surface, the tip of his index finger touching the tip of the extended thumb, the thumb in the plane of the extended arm. Using the anthropometer, measure the horizontal distance from the vertical surface to the tip of the thumb.

15. *Span*: Subject stands erect, his arms and hands extended laterally and horizontally. The longest finger of one hand is touching a vertical surface. Using the anthropometer, measure the horizontal distance from the vertical surface to the tip of the longest finger of his other hand.

16. *Humeral Breadth, Right*: Subject bends his elbow at about a right angle. Applying firm pressure to the tips of the spreading caliper, measure the maximum breadth between the humeral epicondyles.

17. *Humeral Breadth, Left*: Same as Humeral Breadth, Right, Item 16.

18. *Femoral Breadth, Right*: Subject sits with his knees bent at about right angles. Applying firm pressure to the tips of the spreading caliper, measure the maximum breadth between the femoral epicondyles.

19. *Femoral Breadth, Left*: Same as Femoral Breadth, Right, Item 18.

20. *Sitting Height*: Subject sits erect looking directly forward (head oriented in the Frankfort plane). With the anthropometer arm firmly touching the scalp, measure the vertical distance from the sitting surface to the top of the head.

21. *Knee Height, Sitting*: Subject sits, his feet resting on a surface so that the knees are bent at about right angles and the thighs horizontal. Using the anthropometer, measure the vertical distance from the footrest surface to musculature of the right knee directly above the lateral juncture of the posterior surfaces of the upper and lower leg.

22. *Bideltoid Breadth*: Subject sits erect, his upper arms hanging at his sides, and the elbows bent so that the lower arms are horizontal. Using the beam caliper, measure the horizontal distance between the maximum lateral protrusions of the right and left deltoid muscles.

23. *Buttock-Knee Length*: Subject sits erect, his feet resting on a surface adjusted so that the knees are bent at about right angles and the thighs are horizontal and parallel. Using the beam caliper, measure the horizontal distance from the rearmost surface of the right buttock to the front surface of the right kneecap.

SKINFOLDS

24. *Triceps*: Subject stands with his arms relaxed. Grasping a skinfold midway between acromion and the tip of the olecranon (located with the elbow flexed 90 degrees) on the back of the right arm and parallel to the long axis of the arm, measure the thickness of the skinfold with a Lange skinfold caliper.

25. *Juxt nipple*: Subject stands relaxed. Grasping a skinfold about midway between the right nipple and the right anterior axillary crease and parallel to the lines of Lynd, measure the thickness of the skinfold with a Lange skinfold caliper.

26. *Subscapula*: Subject stands relaxed. Grasping a skinfold just below the inferior angle of the right scapula, parallel to the lines of Lynd, measure the thickness of the skinfold with a Lange skinfold caliper.

27. *Grip Strength III*: Same as Grip Strength I, Item 2.

References

Anthropology Section, "Maximum Forces exerted on Aircraft Controls," Aerospace Medical Laboratory, Wright-Patterson Air Force Base, Ohio. Pages 564-567 in Morgan, Cook, Chapanis and Lund (Editors), *Human Engineering Guide to Equipment Design*, New York-Toronto-London: McGraw-Hill, 1963.

Asmussen, E., O. Hansen, and O. Lammert, *The Relation Between Isometric and Dynamic Muscle Strength in Man*, Communication No. 20, Danish National Association for Infantile Paralysis, Hellerup, 1965.

Asmussen, E. and K. Heebøll-Nielsen, *Isometric Muscle Strength of Adult Men and Women*, Comm. No. 11, Dan. Nat. Assn. for Infant. Paral., 1961.

Asmussen, E. and K. Heebøll-Nielsen, "Isometric Muscle Strength in Relation to Age in Men and Women," *Ergonomics*, Vol. 5, No. 1, pp 167-169, 1962.

Ball, J. R., C. Q. Rich, and E. L. Wallis, "Effects of Isometric Training on Vertical Jumping," *Research Quarterly*, Vol. 35, No. 3, pp 231-235, 1964.

Bender, J. A. and H. M. Kaplan, "Determination of Success or Failure in Dynamic (Isometric) Movements by Isometric Methods," *Research Quarterly*, Vol. 37, No. 1, pp 3-8, 1966.

Berger, R. A., "Comparison of Static and Dynamic Strength Increases," *Research Quarterly*, Vol. 33, No. 3, pp 329-333, 1962.

Berger, R. A., "Effects of Dynamic and Static Training on Vertical Jumping Ability," *Research Quarterly*, Vol. 34, No. 4, pp 419-424, 1963.

Berger, R. A. and J. M. Henderson, "Relationship of Power to Static and Dynamic Strength," *Research Quarterly*, Vol. 37, No. 1, pp 9-13, 1966.

Caldwell L. S., *The Effect of Elbow Angle and Back Support Height on the Strength of Horizontal Push by the Hand*, Report No. 378, U. S. Army Medical Research Laboratory, Fort Knox, Kentucky, 1959a.

Caldwell, L. S., *The Effect of the Spatial Position of a Control on the Strength of Six Linear Hand Movements*, Report No. 411, U. S. Army Medical Research Laboratory, Fort Knox, Kentucky, 1959b.

Caldwell, L. S., *The Effect of Foot-Rest Position on the Strength of Horizontal Pull by the Hand*, Report No. 423, U. S. Army Medical Research Laboratory, Fort Knox, Kentucky, 1960.

Caldwell, L. S., *The Relationship between the Maximum Force Exertable by the Hand in a Horizontal Pull and the Endurance of a Sub-maximal Response*, Report No. 470, U. S. Army Medical Research Laboratory, Fort Knox, Kentucky, 1961.

Caldwell, L. S., "Body Stabilization and the Strength of Arm Extension," *Human Factors*, Vol. 4, No. 3, pp 125-130, 1962.

Caldwell, L. S., "The Load-Endurance Relationship for a Static Manual Response," *Human Factors*, Vol. 6, No. 1, pp 71-79, 1964a.

Caldwell, L. S., "Body Position and the Strength and Endurance of Manual Pull," *Human Factors*, Vol. 6, No. 5, pp 479-484, 1964b.

Chui, E. F., "Effects of Isometric and Dynamic Weight-Training Exercises Upon Strength and Speed of Movement," *Research Quarterly*, Vol. 35, No. 3, pp 246-257, 1964.

Clarke, D. H., "Strength Recovery from Static and Dynamic Muscular Fatigue," *Research Quarterly*, Vol. 33, No. 3, pp 349-355, 1962.

Clarke, D. H., "Effect of Preliminary Muscular Tension on Reaction Latency," *Research Quarterly*, Vol. 39, No. 1, pp 60-66, 1968.

Colgate, J. A., "Arm Strength Relative to Arm Speed," *Research Quarterly*, Vol. 37, No. 1, pp 14-22, 1966.

Damon, A., H. W. Stoudt, and R. A. McFarland, *The Human Body in Equipment Design*, Cambridge, Massachusetts: Harvard University Press, 1966.

Dempster, W. T., *Space Requirements of the Seated Operator*, WADC Technical Report 55-159, Aerospace Medical Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, 1955.

Dempster, W. T., "Analysis of Two-Handed Pulls using Free Body Diagrams," *Journal of Applied Physiology*, Vol. 13, No. 3, pp 469-480, 1958.

Dempster, W. T., "Free-Body Diagrams as an Approach to the Mechanics of Human Posture and Motion," Chapter 5 (pp 81-135) in Evans et al., *Biomechanical Studies of the Musculo-Skeletal System*, Springfield, Illinois: C. C. Thomas, 1961.

Dern, R. J., J. M. Levene, and H. A. Blair, "Forces Exerted at Different Velocities in Human Arm Movements," *American Journal of Physiology*, Vol. 151, No. 2, pp 415-437, 1947.

Fox, K., *The Effect of Clothing on Certain Measures of Strength of Upper Extremities*, TR EP-47, Hq Quartermaster Research and Engineering Command, U. S. Army, Natick, Massachusetts, 1957.

Fox, W. F., *Body Weight and Coefficient of Friction as Determiners of Pushing Capability*, Human Engineering Special Studies Memorandum No. 17, Personnel Subsystems, Lockheed-Georgia Company, Marietta, Georgia, 1967 and Personal Communication.

Garrett, J. W., M. Alexander, and W. G. Bennett, *Two-Handed Retention on Various Handle Configurations*, AMRL Technical Report, 67-63, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, 1967.

Gentry, G. G. and R. B. Randall, *A Rapid Tactical Mine-Planting System: How Force Lever Affects Lever-Throwing Time*, Technical Note 8-66, U. S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, 1966.

Harrison, J. Y., "The Effect of Various Motion Cycles on Human Power Output," *Human Factors*, Vol. 5, No. 5, pp 453-465, 1963.

Hertel, H., *Determination of the Maximum Control Forces and Attainable Quickness in the Operation of Airplane Controls*, Technical Memorandum No. 583, National Advisory Committee for Aeronautics, Washington, D. C., 1930.

Hertzberg, H. T. E., "The Conference on Standardization of Anthropometric Techniques and Terminology," *American Journal of Physical Anthropology*, Vol. 28, No. 1, pp 1-16, 1968.

Hertzberg, H. T. E., E. Churchill, C. W. Dupertuis, R. M. White, and A. Damon, *Anthropo-*

metric Survey of Turkey, Greece, and Italy, AGARDograph No. 73, New York: Macmillan Company, 1963.

Hertzberg, H. T. E., G. S. Daniels, and E. Churchill, *Anthropometry of Flying Personnel — 1950*, WADC Technical Report 52-321, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, 1954.

Hunsicker, P. A., *Arm Strength at Selected Degrees of Elbow Flexion*, WADC Technical Report 54-548, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio 1955.

Hunsicker, P. A., *A Study of Muscle Forces and Fatigue*, WADC Technical Report 57-586, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, 1957.

Hunsicker, P. A. and G. Greey, "Studies in Human Strength," *Research Quarterly*, Vol. 28, No. 2, pp 109-122, 1957.

Ikai, M. and A. H. Steinhaus, "Some Factors Modifying the Expression of Human Strength," *Journal of Applied Physiology*, Vol. 16, No. 1, pp 157-163, 1961.

Kogi, K., E. A. Mueller, and W. Rohmert, "Die relative Wirkung isometrischen und statischen Trainings auf die Ausdauer bei dynamischer Arbeit," *Int. Z. angew. Physiol.*, Vol. 20, No. 6, pp 465-481, 1965.

Konz, S. A. and R. A. Day, "Design of Controls Using Force as a Criterion," *Human Factors*, Vol. 8, No. 2, pp 121-127, 1966.

Kroemer, K. H. E., *Was man von Schaltern, Kurbeln und Pedalen wissen muss. Auswahl, Anordnung und Gebrauch von Betaetigungsteilen*; Berlin-Koeln-Frankfurt: Beuth, 1967a.

Kroemer, K. H. E., *Maximal Static Force Versus Stress Measurements as Criteria for Establishing Optimal Work Conditions*, Reprints of the Annual Scientific Meeting of the Aerospace Medical Association, April 10-13, 1967, pp 166-167, 1967b.

Kroemer, K. H. E., *Human Strength: Terminology, Measurement and Interpretation of Data*. AMRL-TR-69-9, Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio, 1969.

Kroemer, K. H. E. and J. M. Howard, *A Note on Strength Measurements*. AMRL-TR-68-144, Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio, 1968.

Lehmann, G., *Praktische Arbeitsphysiologie*, Second Edition, Stuttgart: Thieme, 1962.

Martens, R. and B. J. Sharkey, "Relationships of Phasic and Static Strength and Endurance," *Research Quarterly*, Vol. 37, No. 3, pp 435-437, 1966.

McCormick, E. J., *Human Factors Engineering*, New York-San Francisco-Toronto-London: McGraw-Hill, 1964.

Molbeck, S., *Average Percentage Force at Repeated Maximal Isometric Muscle Contractions at Different Frequencies*, Comm. No. 16, Dan. Nat. Assn. for Infant. Paral., 1963.

Morgan, C. T., J. S. Cook, A. Chapanis and M. W. Lund, *Human Engineering Guide to Equipment Design*, McGraw-Hill Book Company, New York-Toronto-London, 1963.

Mueller, E. A., "Physiology of Muscle Training," *Rev. canad. Biol.*, Vol. 21, Nos. 3/4, pp 303-313, 1962.

Mueller, E. A., "Muskeltraining und koerperliche Leistungsfahigkeit," *Umschau in Wissenschaft und Technik*, No. 18, pp 561-563, (Reprint) 1964.

- Murrell, K. F. H., *Ergonomics*, London: Chapman and Hall, 1965.
- Pearson, J. R., D. R. McGinley, and L. M. Butzel, "A Dynamic Analysis of the Upper Extremity: Planar Motions," *Human Factors*, Vol. 5, No. 1, pp 59-70, 1963.
- Petersen, F. B., *The Effect of Training with Varying Work Intensities on Muscle Strength and Circulatory Adaptation to Work*, Comm. No. 12, Dan. Nat. Assn. for Infant. Paral., 1962.
- Pierce, B. F., "Manual Force Capabilities of a Pilot in a Full-Pressure Suit: Techniques of Measurement and Data Presentation," *Engineering and Industrial Psychology*, Vol. 2, No. 1, pp 27-33, 1960.
- Rasch, P. J. and W. R. Pierson, "Isotonic Training and Isometric Strength," *Precept. Mot. Skills*, Vol. 16, pp 229-230, 1963.
- Roberts, D. F., K. A. Provins, and R. J. Morton, "Arm Strength and Body Dimensions," *Human Biology*, Vol. 31, No. 4, pp 334-343, 1959.
- Rohmert, W., "Die Armkraefte des Menschen im Stehen bei verschiedenen Koerperstellungen," *Int. Z. angew. Physiol. einschl. Arbeitsphysiol.*, Vol. 18, pp 175-190, 1967a.
- Rohmert, W., "Ermittlung von Erholungspausen fuer statische Arbeit des Menschen," *Int. Z. angew. Physiol. einschl. Arbeitsphysiol.*, Vol. 18, pp 123-164, 1967b.
- Rohmert, W., "Untersuchung statischer Haltearbeiten in achtstuendigen Arbeitsversuchen," *Int. Z. angew. Physiol. einschl. Arbeitsphysiol.*, Vol. 19, pp 35-55, 1961.
- Rohmert, W., *Maximalkraefte von Maennern im Bewegungsraum der Arme und Beine*, Forschungsbericht No. 1616 des Landes Nordrhein-Westfalen. Koeln-Opladen: Westdeutscher Verlag, 1966.
- Scherrer, J., *Physiologie de Travail (Ergonomie)*, Paris: Masson et Cie, 1967.
- Singh, M. and P. V. Karpovich, "Isotonic and Isometric Forces of Forearm Flexors and Extensors," *Journal of Applied Physiology*, Vol. 21, No. 4, pp 1435-1437, 1966.
- Smith, L. E., "Effects of Muscular Stretch, Tension, and Relaxation upon the Reaction Time and Speed of Movement of a Supported Limb," *Research Quarterly*, Vol. 35, No. 4, pp 546-553, 1964.
- Streimer, I. and W. E. Springer, *Work and Force Producing Capabilities of Man*, Document No. D2-90245, Boeing Airplane Company, Seattle, 1963.
- Tornvall, G., "Assessment of Physical Capabilities: With special reference to the evaluation of maximal voluntary isometric muscle strength and maximal working capacity," *Acta Physiologica Scandinavica*, Vol. 53, Supplement 201, 1963.
- Watt, D. N., *Maximum Forces Exerted on a Stick Type Control*, Report 63-RD-1, RCAF Institute of Aviation Medicine, Toronto, Canada, 1963.
- Wilkie, D. R., "Man as a Source of Mechanical Power," *Ergonomics*, Vol. 3, No. 1, pp 1-6, 1960.
- Woodson, W. E. and D. W. Woodworth, *Human Engineering Guide for Equipment Designers*, Second Edition, Berkeley, Los Angeles: University of California Press, 1964.